A STUDY OF THE RENAL CIRCULATION, WITH SPECIAL REFERENCE TO ITS FINER DISTRIBUTION.

by

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In studying the literature on the blood supply of the kidney, one is impressed by the lack of uniformity in the descriptions by various writers. Certain elasticity as to terminology is naturally to be expected, but when one realizes that the source of nutrient supply to the medulla of the kidney is still questioned -- surprize gives place to interest.

As far back as 1842 Bowman[1] stated, "All the blood of the renal artery (with the exception of a small quantity distributed to the capsule, surrounding fat, and the coats of the larger vessels) enters the capillary tufts of the malpighian bodies; thence it passes into the capillary plexus surrounding the uriniferous tubes, and it finally leaves the organ through the branches of the renal vein." This able observer therefore entertained no doubt that the vascular supply of the medulla came from the efferent vessels of glomeruli.

Gerlach[2], Kolliker[3], Ludwig[4], and Gross[5] support this view, together with Huber[6], who worked on mammalian kidneys.

Huschke[7] and a few other observers consider that the nutrient arteries to the medulla originate in the capillary plexus around the tubules of the renal cortex.

The generally accepted teaching originally laid down by Virchow[8], and later upheld by Golubew[9], is that

nutrient vessels arise directly from the arcuate arteries and pass down between the collecting tubules of the medulla. These vessels are in no way associated with glomeruli and are termed Arteriae Rectae Verae. Other fine straight vessels also enter the medulla, but differ by arising from glomeruli, and are called the Arteriae Rectae Spuriae.

A desire for a better understanding of the vascular supply of the kidney, with the added possibility of settling one's conviction on the points of variance, prompted the following investigation.

MATERIAL.

The material for this investigation was derived from Human Autopsy - varying in age from birth to 75 years and obtained 6 to 24 hours after death. Forty-two kidneys in all were studied. Of these 11 were prepared for the observation of the minuter structures, i.e., glomeruli, capillary plexuses, etc. Comparative studies were carried out in the following animals, and the numbers of kidneys examined in each species indicated: Dog, 38; cat, 24; rabbit, 19; guinea pig, 16; rat, 15. Injections were also made of monkey, deer, sheep and pig. The kidneys of these animals were usually obtained fresh, but in some instances had been kept in the ice-box more than 12 hours.

METHOD.

It was decided to make studies of the circulation by means of the celluloid corrosion method, since this method possesses the following advantages:

1. The gross architecture as well as the minutest ramification of the vascular tree can be demonstrated.
2. Differentiation of structure can be clearly shown by the introduction of a dye.
3. The specimens prepared to show gross structure are not brittle nor easily distorted. They are permanent, light, and resilient, and can be handled; excellent, therefore, for demonstration purposes.
4. The ramifications of vessels, no matter how tortuous or numerous, can be easily traced throughout to their ultimate distributions.

Explanation of Celluloid Corrosion Method.

The medium employed consists of a solution of celluloid in acetone. As acetone readily combines with water, the celluloid is rapidly precipitated out of solution whenever water is encountered. Thus by injecting the celluloid solution into cavities or the lumen of blood vessels where moisture is present, one soon obtains a deposition of celluloid forming a cast.

By macerating the parenchyma of an organ whose cavity or blood vessels have been so injected, the celluloid cast is revealed. Hydrochloric acid is the corroding element used, since towards celluloid it is practically inert.

MATERIALS FOR INJECTION MASS.

As recommended by Huber, who modified the technique described by Krassuskaja[10], a stock solution was at first employed as follows:

Acetone, C.P.	600 c.c.
Celloidin	30 grms.
Camphor	20 "

later, thinner solutions of celluloid were used with success, where the injection of capillaries was sought. The minimum effective dilution arrived at was 3 parts of celluloid in acetone 100 parts.

For the preparation of specimens showing gross structure, heavier solutions were used, i.e., 10-part and 20-part solutions.

As Celloidin (Schering) or Bioloid (Bausch & Lomb) or Parlodion (DuPont) are somewhat expensive and not always readily obtained on the market, old x-ray films were experimentally substituted in the same proportions and gave just as good results in the preparation of coarser specimens. For fine injections, however, the solutions of x-ray films were not so pleasing.

PREPARATION OF THE INJECTION SOLUTIONS.

It is advisable to make up solutions of varying strength in bulk. The following have proved the most useful:

A.	Acetone	100 c.c.	For fine injections, i.e., to show detailed structure, as (a) glomeruli; (b) capillaries.
	Celloidin	3 grms.	
	Camphor	2 grms.	
B.	Acetone	100 c.c.	
	Celloidin	4 grms.	
	Camphor	3 grms.	
C.	Acetone	100 c.c.	For coarse injections, i.e., to show gross structure, as (a) main vascular trunks; (b) renal pelvis and ureter.
	X-ray films	10 grms.	
	Camphor	8 grms.	
D.	Acetone	100 c.c.	
	X-ray films	20 grms.	
	Camphor	15 grms.	

The x-ray films are thoroughly washed to remove emulsion, cut into suitable strips, and dried. The Celloidin as supplied in bottles should also be thoroughly dried before use.

To the acetone, C.P., add the celloidin or x-ray films and place the container in a mechanical shaker till completely dissolved. The celloidin in the 3-part and 4-part solutions dissolves in about three hours. The x-ray films do not completely go into solution for 12 hours or so.

At the conclusion of this stage add the camphor. Camphor makes the celloidin less brittle and somewhat more translucent.

APPARATUS.

From the stock containers the solutions are transferred as required to pressure bottles of 250 c.c. capacity. (See Fig. 1). The bottles have wide mouths with rubber stoppers, through which two glass tubes pass, one reaching only through the thickness of the stopper, the other well down almost to the bottom of the bottle. The glass tubes are bent for convenience to the horizontal just after emerging from the stopper, and onto each is slipped a short length of rubber tubing carrying a connecting glass tube. The application of small screw clamps on these two portions of rubber tubing renders the bottle air-tight. To insure against "blow-outs" at high pressures it is necessary to have the rubber stoppers of the bottles thoroughly fixed down by string or wire.

It is advisable to have a number of these bottles on hand, filled, ready for use.

Colouring Agents. - The only suitable one is Alkanin* -- a resin dye, soluble in acetone and unaffected by strong hydrochloric acid.

A small portion of the material is ground up in a mortar, then dissolved in acetone. About 50 c.c. of this

*Fettlosliches Roth. Grueber, also written "Alcanin."

concentrated colouring solution is sufficient to colour a large quantity of the celluloid solution, the amount of dye depending on depth of colour required.

For the differential demonstration of fine structures where a thin solution of celluloid is used, a relatively larger quantity of dye is required than when the heavier injection mass is employed.

It will be found more convenient to add the dye solution directly to the celluloid solution in the 250 c.c. pressure bottles. Depth of colour can thus be more easily regulated to immediate requirements.

Cannulae, - A stock of glass cannulae of all sizes and also of connecting tubes is essential. Much of the success in this line of investigation depends upon having a large and varied supply of carefully prepared cannulae.

Power for injections. - The power for injections was obtained from a supply of compressed air, pressure being regulated by a mercury manometer attached to a Woulff bottle. (See Fig. 1).

Pressures employed. - (A) For preparation of specimens to show gross structure:

1. Arterial	200-300 mm. of Hg.
2. Venous	80-100 " " "
3. Renal pelvis	50- 80 " " "

(B) For preparation of specimens to show fine structure:

1. Arterial 350-600 mm. of Hg.
2. Venous 100-200 " " "

Amount of pressure employed would vary with size of organ; lower pressures for smaller kidneys, and vice versa.

PREPARATION OF SPECIMEN.

Experimentation demonstrated the advisability of a thorough irrigation of the organ with a solution of normal salt before proceeding to injection. The irrigation is carried out through the arterial side and considered sufficient when the outflow from the vein comes clear.

Benefits of this preliminary procedure:

1. Removes blood clot.
2. Promotes more rapid precipitation of the celluloid out of the acetone solution.
3. Better casts are obtained. The larger vessels in the corrosion specimens show more cylindrical trunks.
4. Torn or divided collateral vessels can be easily detected by leakage of the fluid and ligated, thus establishing a closed circuit.

Better casts are similarly obtained of the renal pelvis by washing out through the ureter with a gentle filling and emptying.

AIR EMBOLISM DURING INJECTION.

The greatest care should be taken to exclude the entrance of air during irrigation and at subsequent injection.

Air embolism is fatal to the production of a perfect specimen. It is best avoided by having the selected cannula attached first to the outflow tube of the pressure bottle and this in turn connected with the air pressure system. By raising the air pressure and removing the proximal screw clamp a definite positive pressure is set up within the bottle. Then by gently opening the distal clamp the contents of the bottle begin to be driven out. A varying amount of air comes first, then pure solution. Wait till pure solution reaches the tip of the cannula, then shut down the distal clamp. The injection system is now free of air and the cannula ready for insertion.

TECHNIQUE OF INJECTION.

Foreword.-- No corrosion preparation - worthy of the name - can ever be made unless the circuit is a closed one. Waste of time, material and disposition invariably attends any continued attempt to close a broken circuit.

As already stated, take the opportunity afforded by the saline irrigation to tie off any leaks or places of doubtful oozing before proceeding to employ the injection solution.

Injection is made directly into the renal vessels. Where, however, as in guinea pigs and rats, the size of the renal vessels renders such a procedure difficult, the abdominal aorta or inferior vena cava is selected. In such instances it is well to ligate the main trunk on the farther side of the origin of the renal vessels. This prevents dissipation of pressure.

The same cannula as was employed during the saline irrigation should again be used - provided it proved of correct size - connected to a pressure bottle containing the celluloid solution of desired strength. Proceed as before to exclude air, then insert and tie in the cannula. Before releasing the distal clamp, run the pressure up to the required height.

Better results are obtained when the full pressure to be used is thrown into the organ as quickly as possible (Huber). Maintain this pressure for at least 10 to 15 minutes, then close off the proximal screw clamp. A positive pressure is thus kept up within the pressure bottle and it may now be disconnected from the air pressure source and removed along with the specimen to a convenient place where the process of injection and "setting" may continue to completion.

"Setting." - Time required for this varies. When a fine injection has been made in order to study the capillaries, only one hour or so need be allowed before proceeding with corrosion, but with coarser preparations a

delay of 12 hours is necessary. During this period of "setting" it is advantageous to submerge the organ in water.

CORROSION OR DIGESTION.

Huber advises 75 per cent solution of hydrochloric acid. I have encountered no disadvantage in using the pure or concentrated acid. The commercial article works equally well.

Gross injections should be totally immersed in the acid. Subsequent study of finely injected preparations is facilitated if free hand sections of the organ are made and these placed in the macerating fluid.

Duration in acid, 12 to 48 hours. It is necessary to have complete digestion by the acid, otherwise thorough removal of all parenchymatous debris from the finer structures is not easy and any persistent attempt to do so endangers the integrity of the specimen. Prolonged immersion in acid tends to render the celluloid more friable and should be avoided.

"WASHING OUT."

Removal of the macerated tissue from the celluloid cast is easily accomplished by a stream of water. In the finer preparations the "washing" has been carried out under observation (binocular microscope). A fine drawn-out cannula, attached by a convenient length of rubber tubing to a pressure bottle containing water, is allowed to play

with a gentle intermittent drop flow upon the specimen as it lies in a watch glass or Petri dish covered by water. By this means it is easy to detect and prevent any breaking up or mutilation of the details of a specimen during removal of the digested parenchyma.

PRESERVATION OF SPECIMENS.

Corrosion preparations are best preserved in fluid. Drying tends to wither them and remove that pleasing semi-translucent appearance. This is particularly noticeable with preparations having differential colour.

The following solution has proved satisfactory:

Distilled water	100 c.c.
Formaldehyde	2 c.c.
Glycerin	20 c.c.

Specimens may be mounted in ordinary rectangular glass jars, but look particularly well under large watch glasses. The technique of this process is described in detail by Day[11].

The small microscopic preparations can be conveniently preserved in gelatin, in specially constructed containers, as devised by Shore.[12] The results are most attractive but unfortunately absorb much time in the making. A quicker, almost more efficient way is to combine these two methods and use small sized watch glasses on 2- ~~and~~ 3-inch slides, and gelatin as the medium.

FINDINGS.

Main Distribution.

The main arterial trunk on entering the hilus of the kidney divides up into branches which pursue a course between the pyramids or lobes of the kidney (Figs. 3,5,6). These branches, called the interlobar arteries, group themselves so that a little more than half their number pass to the anterior aspect of the renal pelvis and the remainder pass round posteriorly (Fig. 5). The interlobar arteries are more or less equal in length and uniform in bore and remain so almost to their termination.

Giving off numerous branches, these vessels gain the bases of the pyramids. Here they change their course in such a manner as to form incomplete arterial arches. They now receive the title of arcuate arteries.

Many of the branches given off by the interlobar arteries to the adjacent portion of cortex are really arcuate arteries in miniature, for they obtain the same characteristics in every way (Figs. 6,33,35). Besides these cortical branches the interlobar vessels supply a few nutrient vessels to the surrounding fat, also some intimate vasa vasorum.

Arcuate Arteries.

These, as already indicated, pursue an arched course, the convexity of the arch being outwards or to the periphery of the organ (Fig. 35). It is remarkable

how little of the proverbial "arching" is present in kidneys of individuals below middle age (Fig. 6). The "curving" appears to become more marked as age advances (Fig. 7), especially so if arterio-sclerosis is present. The general appearance of such kidneys (in corrosion preparation) can be likened to a gnarled oak tree (Figs. 9,10). As these arteries proceed they ramify into numerous smaller vessels, each describing a somewhat arched course roughly in the same plane as the parent trunk and parallel to the surface of the kidney (Fig. 33). From the convexities of the main vessel and its numerous branches the small interlobular arteries arise at frequent intervals to pass vertically up through the cortex (Figs. 35,36B).

An arcuate artery and its subdivisions, each rapidly diminishing in caliber, soon become so attenuated that they cease to be able to conform to type. They now, by taking a sudden upward course through the cortex, take on the properties of true interlobular arteries (Figs. 38B,41C). To this abrupt upward termination of the arcuate artery and its radicles is due the appearance of the cortical margin in instances of non-injection of an aberrant or other renal vessel (Fig. 11B).

Having mentioned the interlobular arteries as branches arising abruptly from the convexities of the arcuate vessels, one is left with three types of minor off-shoots to describe.

The first is the occasional small tortuous branching vessel in intimate distribution around the parent trunk - vasa vasorum.

Second, the small straight vessels of varying length, some extremely short, others as long as .75 cm. They arise usually at an acute angle from the main trunk, infrequently from the convex surface, but chiefly from the concave or medullary aspect. The longer ones may even take a course almost parallel to the direction of the main trunk. Each one of these small straight vessels, short or long, ends in one or more glomeruli.

The third type, which has been only very occasionally observed, resembles an afferent vessel as just described under type two. This vessel may show (a) no evidence of a glomerulus or (b) only a small indefinite thickening just proximal to its subdivision into straight medullary branches.

Apart from these branches no evidence of arteriae rectae verae, as usually diagrammed and described, could be found.

Interlobular Arteries.

These arteries pass out from the arcuate vessels at altering angles (Fig. 35). Those that come off from the arcuate vessels toward their termination arise almost at a right angle, whereas passing back toward the origin of the parent stems we notice that the interlobular vessels are given off more and more at an acute angle. This, as

previously stated, appears for the conservation in conveyance of arterial pressure.

In simple unilobed kidneys (sheep, dog, cat, rabbit, rat, etc.) the arrangement of the interlobular arteries is comparatively simple. They almost uniformly run parallel to each other and at right angles to the surface of the organ (Figs. 35,43,44).

The human kidney, however, is multilobed. Most of the lobes are found to be amicably fused at their bases, i.e., the cortex shows no depression to indicate line of fusion. Frequently, however, fusion is not so complete, adjacent lobes remaining partially disassociated. Here the cortex shows a definite depression corresponding to the line of malunion, since it dips down, accompanying the base of each of those lobes. It is to a lesser or greater degree infolded upon itself. These infoldings may be transverse or parallel to the long axis of the kidney and are known as the transverse and longitudinal cortical columns (Bertini), (Fig. 9).

It is at such infoldings of the cortex that we get marked alteration in the general position of the interlobular arteries. The infolded cortex has brought two surfaces into opposition, hence we get two opposing columns of interlobular vessels interdigitating with one another (Fig. 34).

This formation varying in degree gives rise in the human kidney to extraordinary arrangements in the distri-

bution of these cortical vessels (Figs. 36,37,38). In kidneys of this type, showing lobulation, one meets with perforating capsular and aberrant arteries more frequently. The interlobular arteries may remain single or undergo one, two or more subdivisions (Fig. 38). Some of the interlobular vessels have a characteristic straight course resembling the "new shoots" or "fresh growth" of plants and come off from the parent stem at varying angles (Fig. 40). They may terminate in any of the following ways:

(a) As an afferent vessel to a glomerulus (Figs. 38,49-A).

(b) By subdivision into two, three or more afferent glomerular vessels (Fig. 42).

(c) By directly breaking up in the cortex into a plexus of nutrient capillaries.

(d) By passing completely through the cortex and pursuing its course as a peri-renal nutrient vessel - perforating capsular artery (Fig. 12).

It will be observed that (c) and (d) are nutrient vessels which have not first passed through a glomerulus. They will be discussed later.

Branches Given Off by Interlobular Arteries.

1. Numerous small twigs, varying slightly in length, which are given off singly or in groups of two or more, without any uniform interval or arrangement but which all end in glomeruli. These vessels are known as the afferent vessels of the glomeruli (Figs. 36-40).

2. Very occasionally a small twig has been seen to arise between these afferent vessels and by rapidly subdividing form a capillary plexus, i.e., a direct nutrient vessel to the tubules without the interposition of a glomerulus. (Fig. 49-C).

In no instance has one seen any interlobular artery give off a direct nutrient vessel which entered the medulla.

Glomeruli.

A glomerulus is an almost spherical tuft of blood vessels of pre-capillary size. It is formed by an abrupt localized subdivision of the afferent vessel into loops and the convergence of these loops again into a single but smaller vessel - the efferent vessel, which by the exigencies of development has to assume a position alongside the afferent artery at the hilus of the glomerulus.

In a well injected specimen the glomeruli stand out clearly and show on careful inspection numerous convolutions. They simulate closely the beautiful reconstructed wax models prepared and described by Johnston[13]. Occasionally one has observed twin glomeruli resembling those noted by Beer[14].

Situations where glomeruli are found:

1. Glomeruli are found in greatest profusion among the interlobular arteries to which they are attached by the afferent vessels. It seems that the principal duty of an interlobular artery is to bear glomeruli.

On examining some groups of these vessels and their branches covered by glomeruli, one cannot avoid the simile of an apple tree laden with fruit.

2. Glomeruli which arise from the arcuate arteries are peculiar in that they vary not only as to the length of their afferent vessels but also in their own dimensions. Some are about twice the average size of those met with in the cortex. Others again are less than half the average size (Figs. 38,40,44).

The injection method employed may to a certain extent account for this variance, since it is noted that very frequently the glomeruli which appear large are those that have extremely short efferent vessels, and vice versa. The glomerulus that is nearer the source of pressure receives the greater quantity of injection mass. This is doubtful, considering the high pressures used, the suddenness of their application and the duration of injection time.

The Efferent Glomerular Vessels Their Types and Distribution.

According to the position which a glomerulus occupies in relation to the cortex, its efferent vessel varies in method of ramification and distribution.
To facilitate description let us recall that immediately below the capsule of a kidney we have a thin layer of the cortex which contains no glomeruli. This layer is frequently referred to as the cortex corticis or subcapsular

portion of the cortex. It is occupied by portions of the convoluted tubules and their attendant capillary plexuses, as well as larger venous radicles - Stellate Veins. Below this layer we have the cortex proper, containing the interlobular vessels, glomeruli, tubules, etc.

Further down, before the cortex actually meets the medulla, we have a zone which is intermediary in character. This zone contains in addition to the contents of the cortex proper the origins of the interlobular vessels and the smaller arcuate branches. It is referred to as the medullary portion of the cortex.

Below this we come on the base of the pyramid, or medulla.

1. Subcapsular Type.

A glomerulus which arises from the terminal portions of an interlobular artery immediately subjacent to the cortex corticis supplies an efferent vessel which does not immediately divide but pursues a definite upward course, and having entered the subcapsular region, abruptly divides into a complex network of fine branches to supply the convoluted tubules in this region. (Fig. 42-1,48).

2. Cortical Type.

In the cortex proper each glomerulus supplies an efferent vessel. This vessel may immediately subdivide, giving the impression of two direct efferent radicles (Fig. 45-3). In any case these vessels very rapidly break

up to form a dense interlacing network of fine capillaries and distribute themselves around the tubules (Figs. 42-2, 43-B,49-B).

3. Medullary Type.

In the medullary portion of the cortex, where the glomeruli are relatively somewhat larger, we find efferent vessels very different in type from those already described. Having left the glomerulus as a single stem, the efferent vessel abruptly divides into a stream of straight branches of practically uniform caliber. In spite of the multiplicity of these branches their diameter does not appear to be perceptibly diminished. Coursing downward in bundles, these efferent vessels finally distribute themselves between the collecting tubules in the medulla (Figs. 39,42,44).

4. Cortico-medullary Type.

A glomerulus whose efferent vessel combines the characteristics of both the cortical and medullary types is encountered in the deeper portions of the cortex proper, just above the medullary zone. This efferent vessel immediately divides, the upper branch breaks up into a capillary network (cortical type), whereas the lower sends its branches streaming downward to the medulla as straight vessels (medullary type). Golubew and Huber have described this type. (Fig. 51-A&B).

Venous System.

Little need be said at the present time concerning the channels which conduct the blood back from the cortex out through the sinus renalis.

The venous radicles and trunks resemble in their course the arteries which they accompany, and are similarly designated. There is one great point of difference - the various portions of the venous system within the kidney anastomose freely.

In the human kidney there is one central or internal system of vessels - the arcuate veins - into which blood from the cortex, as well as from the pyramids or medulla, flows, thence it passes on by the interlobar veins into the main renal trunk.

In the subcapsular zone or cortex corticis numerous interlobular veins - larger than the others - are found to begin by a central convergence of radially distributed branches immediately below the capsule. These are the so-called stellate veins (Fig. 12-B). Very occasionally an extra capsular vein has been observed to end in one of these branches (Fig. 16). From the under or cortical aspect of these branches small anastomotic radicles pass down to reach the beginnings of the ordinary interlobular veins (Fig. 23-1). This superficial venous system of the cortex corticis is amplified in the dog, and still more so in the cat, where there is a separate and distinct system developed (first noted by A. E. Belt). The

illustrations clearly depict the arrangement (Figs. 26, 27,28). Draining from the capillary plexuses around the convoluted tubules, the interlobular veins empty into the arcuate veins on their convex or upper aspect. From a fine venous network around the openings of the collecting tubules at the papillae of the pyramid, as well as from the line of reflexion of the minor calyx, straight vessels commence - venae rectae - and pursuing their course between the collecting tubules of the medulla, empty into the under or concave surface of the arcuate veins (Figs. 45-7, 46-F,52).

DISCUSSION.

No discussion is necessary concerning the main vascular distribution within the substance of the kidney. The subject has been thoroughly worked out by numerous competent observers, among whom may be mentioned Hyrtl[15] and Brödel[16].

Corrosion preparations of the kidney circulation emphasize very clearly certain peculiarities of this organ's vascular architecture:

(a) The size of the main renal trunks. It has been calculated that about six times the amount of blood that is absolutely necessary for its own nutrition passes through this organ. Accordingly the vessels have to be large to comply with the demand.

(b) The simple tree-like dichotomous arrangement of the main branches, and that these branches and their numerous subdivisions all come off at an acute angle (Fig. 6).

(c) The extraordinarily rapid diminution in diameter of the vessels during subdivision - a relatively large trunk breaking up into very small branches (Fig. 33). This formation obviously permits of a high pressure being conveyed to, and sustained at, the minute ramifications of the arterial tree.

(d) Further evidence that the vascular arrangement is constructed for the conservation of pressure lies in the fact that each branch of the renal artery is in itself a closed circuit or end artery. Injected corrosion prep-

arations illustrate this point very clearly. If during injection of a kidney a branch of the main trunk or an aberrant vessel be overlooked, the specimen after corrosion shows a complete arterial deficiency of the cortex corresponding to the area supplied by that vessel. The remaining cortical vessels encroach in no way on the gap. The margins of the gap are abrupt and at right angles to the surface of the organ. This abrupt margin is due to the terminal branches of the surrounding arcuate arteries, becoming interlobular vessels and pursuing a vertical course to the surface.

If a large aberrant polar vessel be injected simultaneously with the main arterial trunk and the specimen digested, it is instructive to observe how easily the aberrant vessel with its entire area of ramification can be lifted out from the main portion of the specimen and just as easily replaced. Should a pelvic cast have been made, then removal of the aberrant area will usually expose a minor calyx in part or entire (Figs. 8,11-B). Further, in connection with aberrant arteries it is interesting to observe that the course and direction of their ramifications in the cortex are exactly the reverse of the normal distribution of an intrinsic vessel. They form arches whose convexity is downwards or towards the medulla, and their interlobular arteries on passing back through the cortex take a route almost reversed in direction and parallel to the axis of the entering parent stem. Further-

more, as originally pointed out by Hyrtl, working with corrosion preparations, the two arterial systems of a kidney - the anterior and posterior - are completely separated by the pelvis, and this arrangement prevails "without exception in all mammalia, from the whale to man." (Fig. 5).

Afferent vessels from arcuate arteries which present:- (a) Only a very small or rudimentary glomerulus; (b) no evidence of a glomerulus.

These infrequently occurring vessels have been discussed by Golubew and Huber. They may be purely anomalous or mark some developmental stage. Embryological study might elucidate their type. Golubew describes these small glomerular-like thickenings as "Retia mirabilia renum nova," whereas Huber prefers to consider them as atrophic forms of glomeruli, the process being exemplified at two phases. The appearance of the vessels in these two modifications of this type is similar. The presence or absence of the ?glomerulus seems to make no difference on the character of their course or manner of subdivision into arteriae rectae. They do not in any way resemble the arteriae rectae verae of authors. They are found more often in the cat than in other mammalia (Petraroja[17]).

In man one has encountered extremely few examples of this type, but the ones that were identified show a diminution in number and size of the arteriae rectae arising from their "efferent" vessels. A circumstance which

tends to lend support to the atrophic theory.

Perforating Capsular Arteries:

(a) The perforating capsular artery which arises from one of the main branches in the sinus renalis and which passes completely through the kidney parenchyma without giving off glomerular branches has not been encountered during this investigation.

(b) The interlobular glomerular-bearing artery, however, which terminates by piercing the capsule of the kidney to supply perirenal tissues has been rather frequently met with in the dog and in man (Figs. 12,20). From the kidney of a child aged three months an arcuate artery with branches complete has been isolated (Fig. 12-C). It shows three glomerular-bearing vessels continuing as perforating capsular arteries. In the kidneys of pig, sheep, cat, rabbit and rat these perforating capsular vessels are very infrequently seen.

Nutrient vessels within the cortex which arise from interlobular arteries but are not associated with glomeruli:

Two kinds have been observed -

(a) The direct termination of an interlobular artery by rapid subdivision into a nutrient capillary plexus. This type has been met with but is unusual. It may be regarded as an abbreviated form of the perforating capsular artery.

(b) The small vessel which arises from the trunk of an interlobular artery in place of the usual afferent

glomerular vessel. It has been noted in the dog and sheep as well as in man. It could not be included in the atrophic type seen arising from the arcuate vessels. It is at times even larger than an ordinary glomerular afferent and begins dividing up in a more leisurely fashion than is common to most efferent vessels. There is no semblance of any thickening along its course proximal to division which could suggest past, present or future glomerular potentialities.

The distribution of the efferent glomerular vessels has been described under various types. This differentiation is one of mode only, since the manner of distribution depends upon the varying type of tubular structures encountered at different zones.

At the outset of this investigation one expected to find arteriae rectae verae, but constantly repeating negative findings, not only in human material but also in the series of mammalian kidneys studied, have confirmed one's conviction that if arteriae rectae verae do exist they must be extremely rare. As Huber points out, criticism may be made that the corrosion method may not be a suitable method for showing the presence of these vessels, but "it would seem reasonable to suppose that arteriolae rectae verae should be more readily injected than arteriae rectae spuriae, since in injecting the former it would not be necessary for the injection mass to pass through the glomerular capillaries before reaching the branches and capillaries constituting the arteriolae rectae."

The possibility of mutilation or breaking off of these vessels has received careful attention. All "washing out" of fully injected specimens has been carried out under the binocular microscope, a proceeding which is extremely tedious but fully repaid by the absorbing interest of watching a fine detailed specimen gradually appear as the digested parenchyma disintegrates before the gentle stream of the "water fed" cannula. In "washing out" I usually commence by observing for arteriae rectae in the medulla and tracing these back in continuity to their points of origin.

Errors in observation may have arisen to perpetuate the present-day teaching. Excessive pressures may have been employed with injection methods, leading to extravasation and rupture of the injection mass into venae rectae -- a coincidence which happens not infrequently.

It is only by familiarizing oneself by separate venous injections and by carrying out simultaneous injection of arterial and venous systems in the same specimen - employing a differential colour - that one can arrive at a position from which it is comparatively easy to discriminate the finer radicles of each system (Figs. 45,46). Further, many bundles of efferent vessels from glomeruli, in the medullary portion of the cortex, in their straight downward course into the medulla, encounter the trunks of the arcuate arteries and are obliged to temporarily deflect their course around them. (See diagram

at end). It is not difficult to imagine how in some transverse sections of coloured gelatin injections these straight vessels could be mistaken for branches arising directly from the arcuate vessels, especially so if in these sections the commencement of some of the afferent glomerular branches common to the arcuate vessels were included. A careful inspection of such preparations discloses, however, an appreciable interval between the inferior aspect of the main trunk and these straight vessels. Direct continuity as of a true branch is not shown. To illustrate this point Dr. R. K. Lee-Brown has kindly supplied me with a print of one of his preparations (Fig. 47), which shows a cross section of an arcuate trunk which has actually fallen out. If this bundle of arteriae rectae had arisen directly from the main arcuate trunk, it seems highly probable that they would have been sufficient to hold it in place.

With the exceptional instances (dog, cat, man), as already stated, in which arteriae rectae have been observed to originate without the interposition of a glomerulus, from a branch arising from a minor division of an arcuate artery, one can definitely state that no arteriae rectae verae as described by authors have been observed. If arteriae rectae verae do exist they must be extremely rare and should not receive the prominence in literature that they at present enjoy.

CONCLUSIONS.

That by the celluloid method a satisfactory study of the vascular architecture can be made. The method enables specimens of the circulatory tree in complete continuity to be prepared, and thereby provides excellent and instructive material for demonstration purposes. The ramifications of vessels, no matter how tortuous or numerous, can be easily traced throughout, to their ultimate distributions. The application of this method to the study of the renal circulation has elucidated the following points:

1. That the distribution and course of the main arterial and venous trunks conform in every respect to the accepted teaching.

2. That the arcuate arteries assume only as age advances, the fully arched course usually attributed to them.

3. That glomeruli in considerable numbers arise from even the main arcuate trunks as well as from their subdivisions. These glomeruli vary in size from large to small, some even being "mere shadows of their former selves."

4. That there are four types of efferent glomerular vessels -

a. Subcapsular
b. Cortical
c. Cortico-medullary
d. Medullary

The renal cortex is subdivided into zones by the structural characteristics of component tubular elements. Glomeruli in these varying zones accordingly comply with efferent vessels which are modified in manner of distribution.

(a) The subcapsular glomerulus gives off an efferent vessel which pursues a vertical upward course for an appreciable distance into the cortex corticis before breaking up into a capillary network around the tubules in this non-glomerular zone.

(b) The cortical glomerulus contributes an efferent vessel which immediately subdivides into a capillary plexus.

(c) The cortico-medullary glomerulus, occupying an intermediary zone between the cortex proper and its medullary portion, is far less numerous than the preceding types. Its efferent vessel so subdivides that only a small number of its branches break up to form a capillary plexus for immediate distribution, and the remainder take a straight downward course into the medulla as arteriae rectae.

(d) The medullary glomerulus, somewhat larger than any of the others, supports through its efferent branches the blood supply of the medulla. These branches, arising from one efferent vessel, by rapid subdivision descend in bundles and pursue a straight vertical course

into the medulla. They are the arteriae rectae spuriae of authors.

5. That the parenchyma of the cortex receives in addition to the nutrient efferent glomerular vessels, occasional direct branches from the interlobular arteries, or an interlobular artery may itself terminate by ramifying into a capillary plexus.
These additional non-glomerular sources of nutrient supply are, however, so infrequent as to be negligible from a physiological point of view.

6. That the medulla of the kidney receives its blood supply solely from the efferent branches of the lower glomeruli, i.e., "Arteriae Rectae Spuriae."

An arcuate artery occasionally gives off an exceptional vessel which shows no eivdence of a glomerulus but closely simulates the other glomerular bearing vessels. Apart from this exception - if such it can be called - the present investigation has revealed no evidence of the commonly accepted "Arteriae Rectae Verae."

Numerous direct photographic records are submitted, together with a composite chart, to illustrate and substantiate my findings.

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NOTE: The scale of photographic enlargement for the smaller specimens may be judged by a horizontal or vertical line drawn on the picture thus ⟷ or ↕

The horizontal line denotes the width and the vertical line the height of the actual size of the specimen.

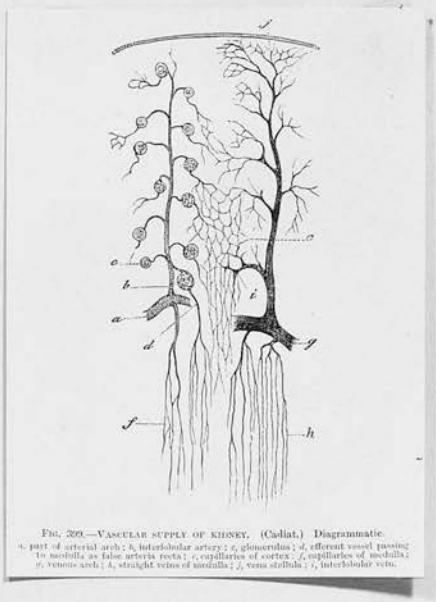


FIG. 389.—VASCULAR SUPPLY OF KIDNEY. (Cadiat.) Diagrammatic.
a, part of arterial arch; *b*, interlobular artery; *c*, glomerulus; *d*, efferent vessel passing to medulla as false arteria recta; *e*, capillaries of cortex; *f*, capillaries of medulla; *g*, venous arch; *h*, straight veins of medulla; *j*, vena stellula; *i*, interlobular vein.

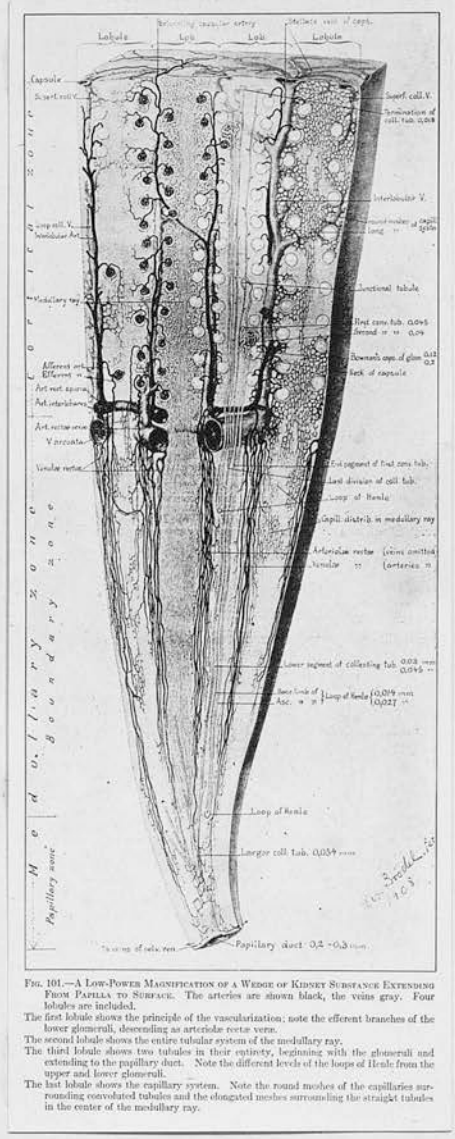


FIG. 101.—A LOW-POWER MAGNIFICATION OF A WEDGE OF KIDNEY SUBSTANCE EXTENDING FROM PAPILLA TO SURFACE. The arteries are shown black, the veins gray. Four lobules are included.
The first lobule shows the principle of the vascularization; note the efferent branches of the lower glomeruli, descending as arteriolæ rectæ veræ.
The second lobule shows the entire tubular system of the medullary ray.
The third lobule shows two tubules in their entirety, beginning with the glomeruli and extending to the papillary duct. Note the different levels of the loops of Henle from the upper and lower glomeruli.
The last lobule shows the capillary system. Note the round meshes of the capillaries surrounding convoluted tubules and the elongated meshes surrounding the straight tubules in the center of the medullary ray.

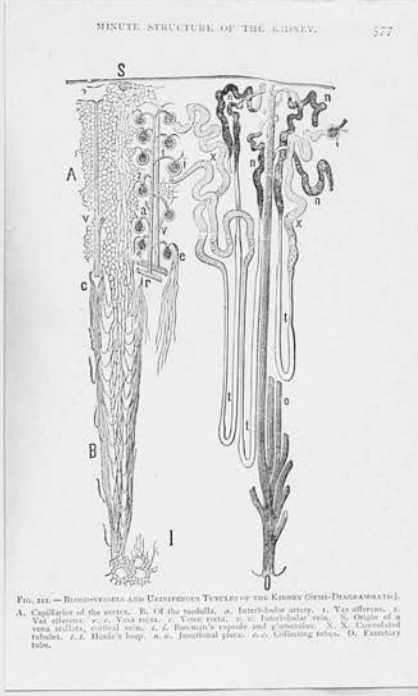


FIG. 391.—BLOOD-VESSELS AND URINIFEROUS TUBULES OF THE KIDNEY (SEMI-DIAGRAMMATIC).
A, Capillaries of the cortex. B, Of the medulla. *a*, Interlobular artery. *v*, Vas afferens. *z*, Vas efferens. *r, r*, Vasa recta. *v, v*, Interlobular vein. S, Origin of a vena stellata, cortical vein. *t, t*, Bowman's capsule and glomerulus. S, S, Convoluted tubules. *l, l*, Henle's loop. *n, n*, Junctional piece. *o, o*, Collecting tubes. O, Excretory tube.

Diagrams showing Renal Circulation, reproduced from well-known text books.
The nutrient supply of the medulla is represented as coming from -

(a) The arteriae rectae of the lower glomeruli.
(b) Vessels arising directly from the concavities of arcuate trunks.
(c) Vessels arising directly from the medullary portions of interlobular arteries (Brödel).

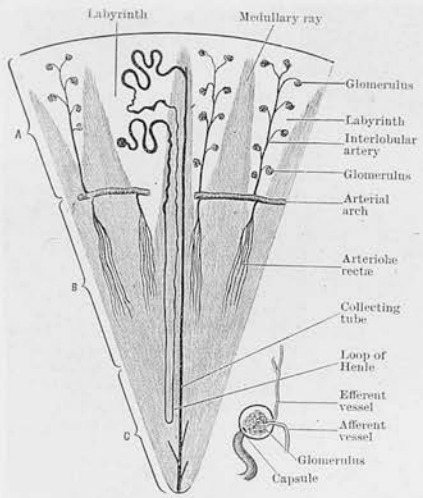


FIG. 806.—DIAGRAMMATIC REPRESENTATION OF THE STRUCTURES FORMING A KIDNEY LOBE.

the middle part of the figure the course of one of the kidney tubules is indicated, and in the lateral parts the disposition of the larger arteries. A, Cortex; B, Intermediate zone; C, Papillary portion.

e diagram at the right-hand side of the lower part of the figure illustrates the connexions of the structures composing a Malpighian corpuscle.

A

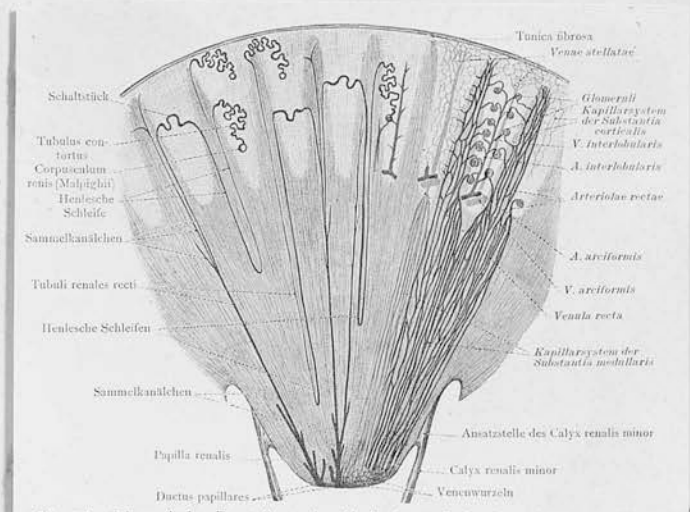


Fig. 835. Schematische Darstellung des Verlaufes und der Anordnung der Harnkanälchen und Blutgefäße in der Niere.

Ren, Niere.

B

Diagrams showing Renal Circulation, reproduced from well-known text books.

A. The nutrient supply to the medulla is here represented as being derived solely from direct straight branches of the arcuate arteries.

B. This diagram (Toldt) is apparently based on Huschke's observation that the arteriae rectae arise from the capillary plexuses surrounding the uriniferous tubules. It requires that the blood after negotiating first a precapillary plexus (glomerulus), then a capillary plexus (convoluted tubules) be collected up into channels which will again be subdivided to form a third plexus to supply the collecting tubules of the medulla before finally entering the venous system.
A unique and unprecedented vascular arrangement!

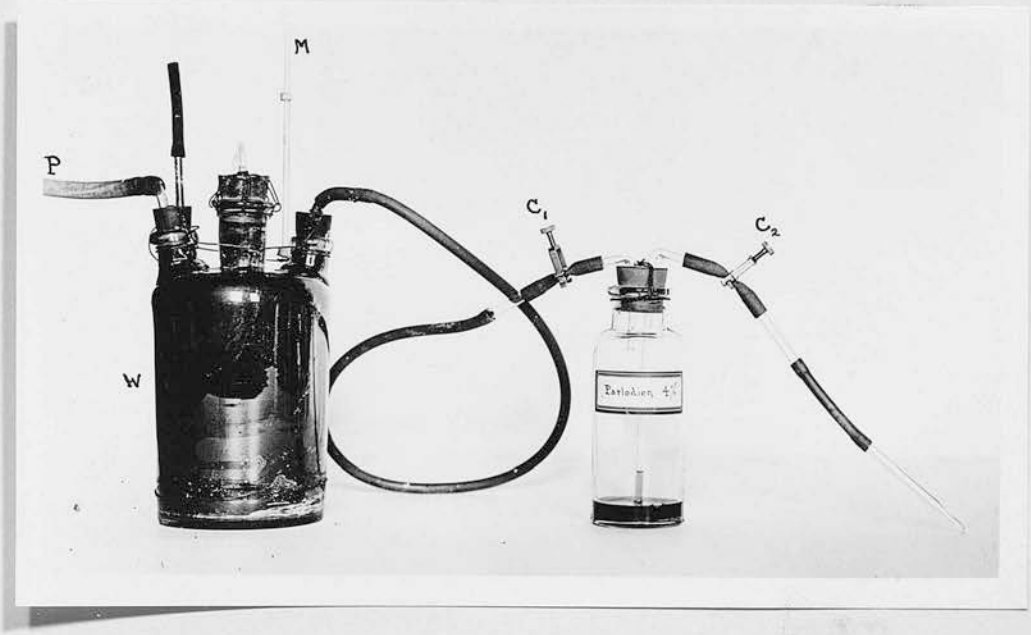


Fig. 1. - Injection Apparatus.
Comprising Woulff's bottle (W) with mercury manometer (M), connected by rubber tubing to pressure bottle.
(To facilitate demonstration only a small amount of Parlodion, coloured with Alkanin, has been left in the pressure bottle).

The pressure bottle as pictured is air-tight and constitutes a convenient unit for temporary storage or immediate use.
Air pressure enters by tube (P).
C_1 - Proximal screw clamp.
C_2 - Distal screw clamp.

Fig. 2 - Human Kidney - child at birth.

V. Vein
A. Artery
U. Ureter

Coarse injection, showing arched distribution of vessels around the numerous minor calyces.

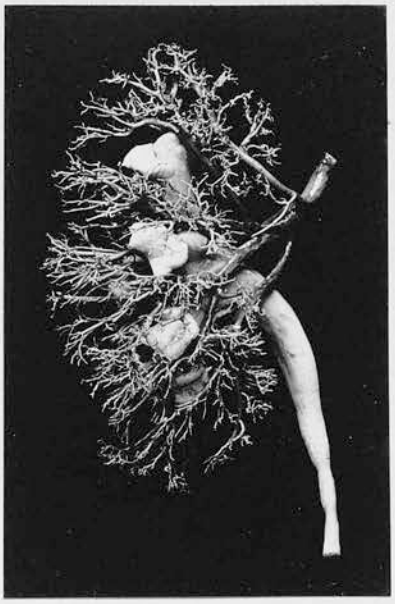


Fig. 3. - Human Kidney - Age 6.
Injection of ureter and pelvis with arterial system (coarse) shows main arterial distribution around calyces.

Fig. 4. - Human Kidney - Child.
Showing gross arterial injection as well as that of pelvis and ureter. The normal narrowing of the ureter at the pelvo-ureteral junction is clearly shown.

Fig. 5. - Human Kidney.
Injection of ureter and arterial system (coarse). To show the complete isolation that exists between the distributions of the anterior and posterior branches of the renal artery, the posterior branch has been displaced.
This is the same specimen as in Fig. 4.

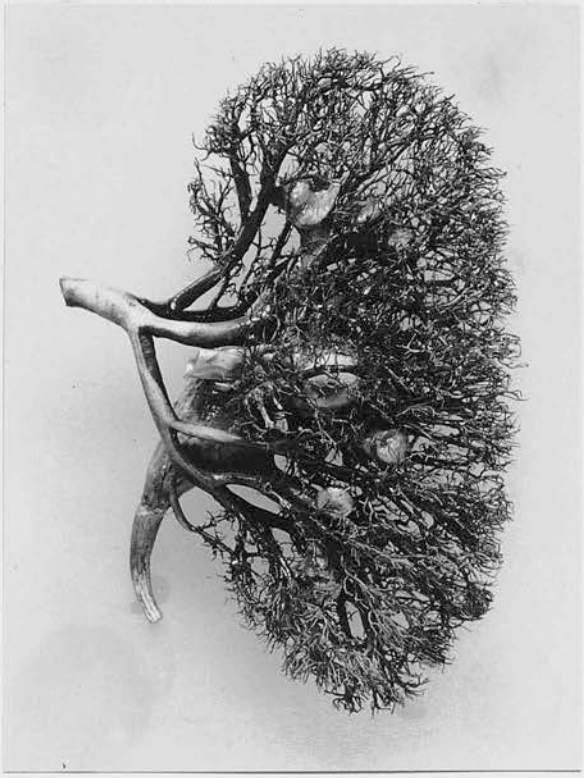


Fig. 6. - Human Kidney - Young adult.
Injection ureter and pelvis with arterial system (coarse). Note the directness of the vessels as they divide and subdivide on to their ultimate distributions. Very little "arching" to be seen.
Compare the uppermost main branch, i.e., passing to summit of upper pole, to the specimen in Fig. 35.

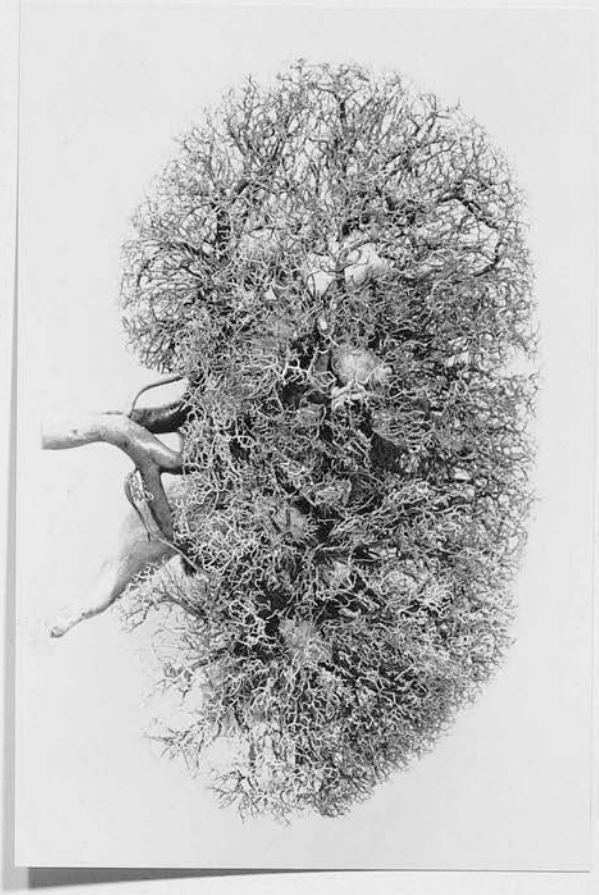


Fig. 7. - Human Kidney - Adult.
Injection of pelvis with arterial system.
See Fig. 8.

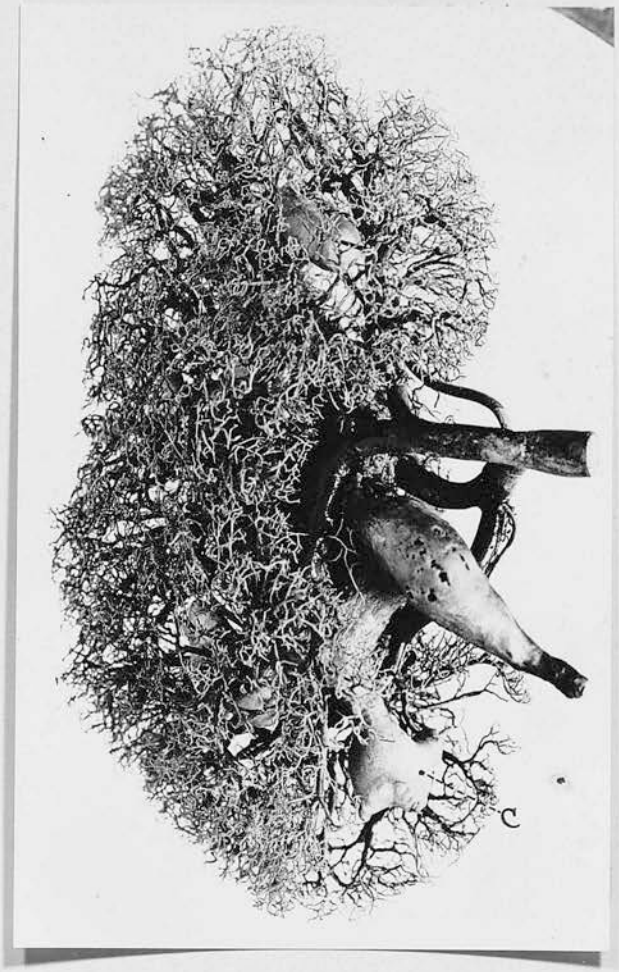
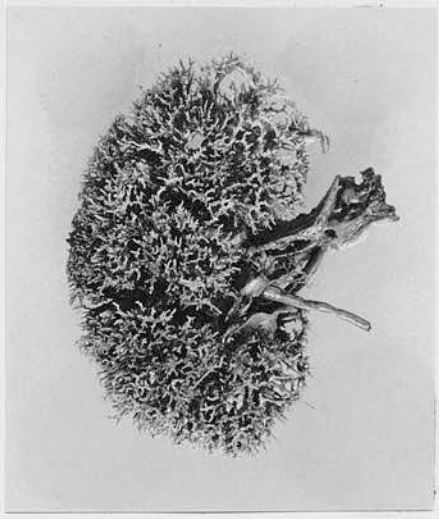


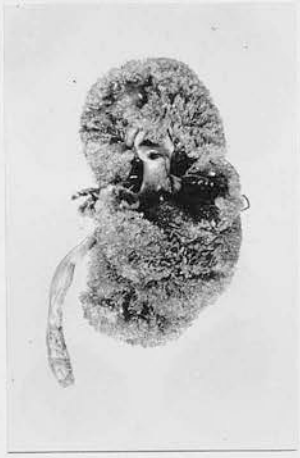
Fig. 8. - Aberrant artery to lower pole (Human kidney).
Injection of ureter and arterial system. The lowest calyx (c) is completely exposed, due to the non-injection of the aberrant vessel.
This is the same specimen as illustrated in Fig. 7.

Fig. 9. - Human Kidney.
Injection of ureter and pelvis with arterial system. From case of arteriosclerosis.
Note here the marked tortuosity of the entire system. The arcuate vessels are especially arched. This kidney also shows across its middle a definite transverse cortical column, where the interlobular arteries interdigitate in a plane parallel to the outer border of the organ. See also Fig. 34.

Fig. 10. - Human Kidney.
Injection of pelvis and arterial system (coarse). From case of arterio-sclerosis.
Vessels show definite gnarled oak appearance.



A



B

Fig. 11. - Human Kidneys.

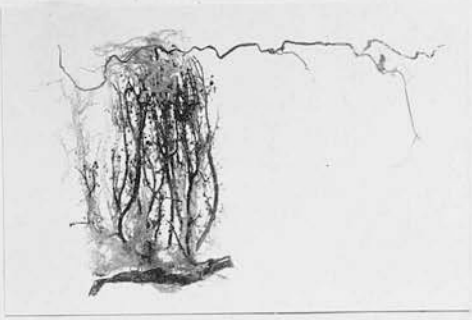
A. From child age 6. Injection of artery and vein (coarse) as well as ureter. There was an aberrant artery to the upper pole which was overlooked during injection, hence the venous arches are discernible here. Note also the two deep furrows passing radially from the hilus to the outer border, subdividing the cortex approximately into thirds. The kidney presented lobulations of foetal type.

B. From child age 3 months. Injection of artery (fine), also ureter. This was a multilobulated kidney with aberrant vessel. The fine aberrant branch was overlooked, with the result shown. An entire calyx is exposed. The cortical border surrounding the gap is clear cut. From the middle of the outer border of the kidney can be seen the arched course of a perforating capsular artery. (Further illustrated in Fig. 12-c).

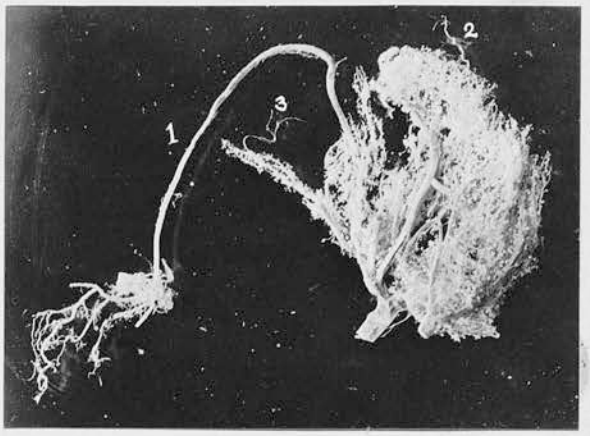
Fig. 12. - Perforating Capsular Arteries.

A

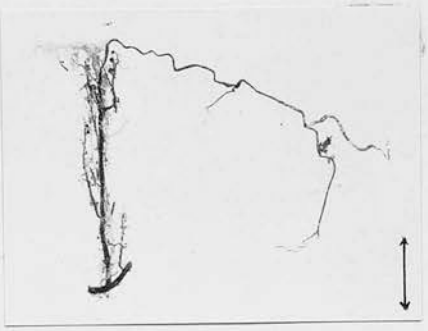
B



C



D



A. (Dog). A branch of a glomerular bearing interlobular artery perforating the cortex to become an extra capsular vessel.
B. (Human). From an arterial and venous injection specimen. Similar type of interlobular vessel perforating the capsule. Note the stellate vein intimately associated with it at the cortex.
C. (Human). From the child's kidney depicted in Fig. 11-B 3 perforating vessels will be observed to arise from the one parent trunk.
D. (Human). A more complete dissection of B, to show relationship to parent stem and stellate vein.

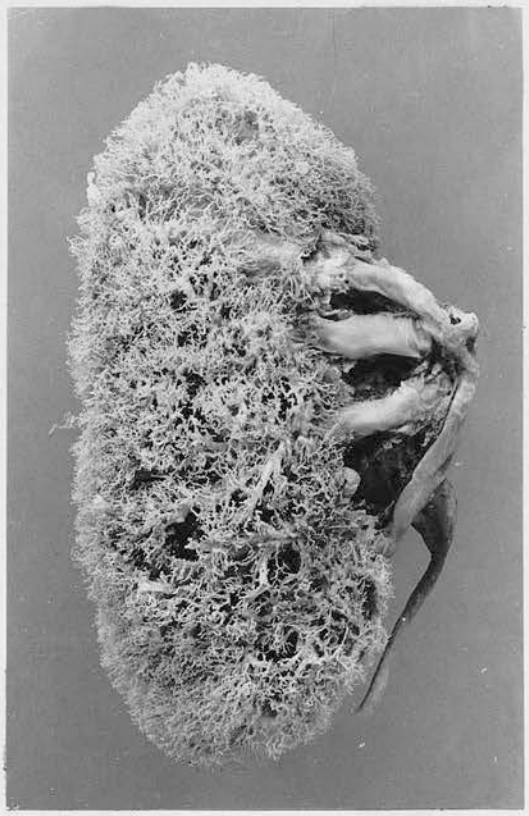


Fig. 13. - Human Kidney.
Injection - Venous
Ureteral.

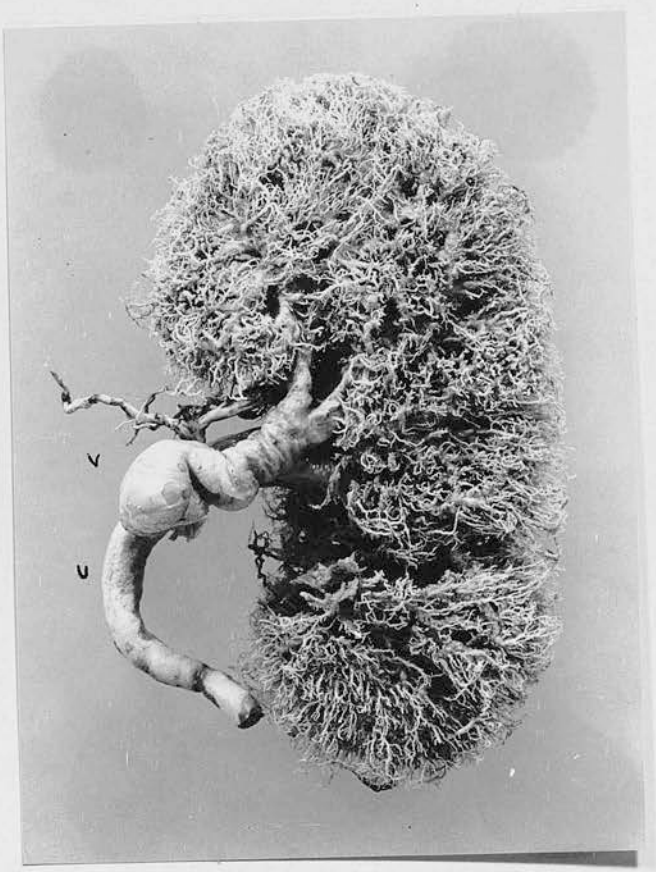


Fig. 14. - Human Kidney.
Injection of vein (v) and ureter (u).

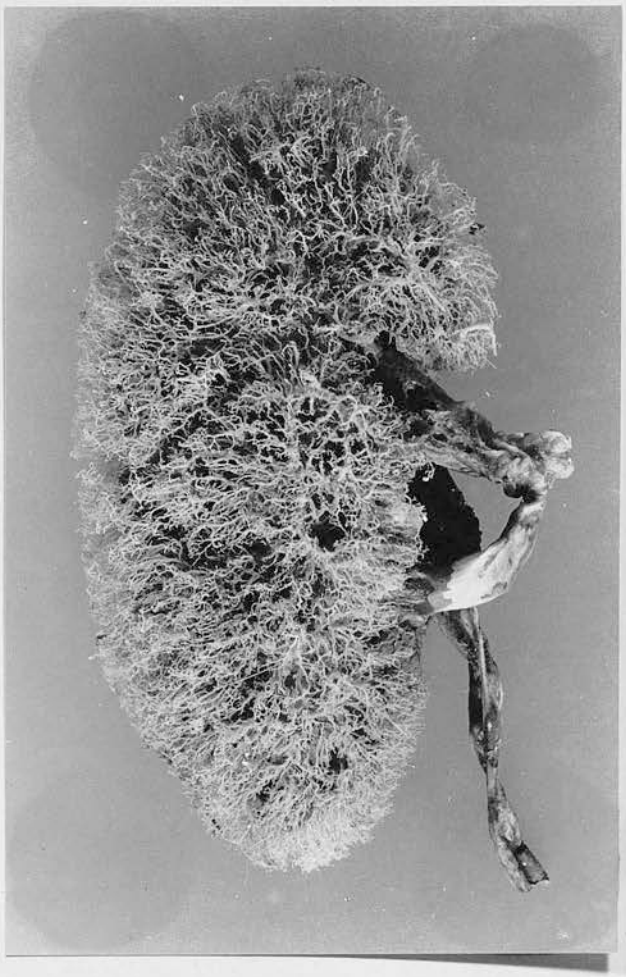


Fig. 15. - Human Kidney.
Injection - Venous
Ureteral.
Shows general venous arrangement.

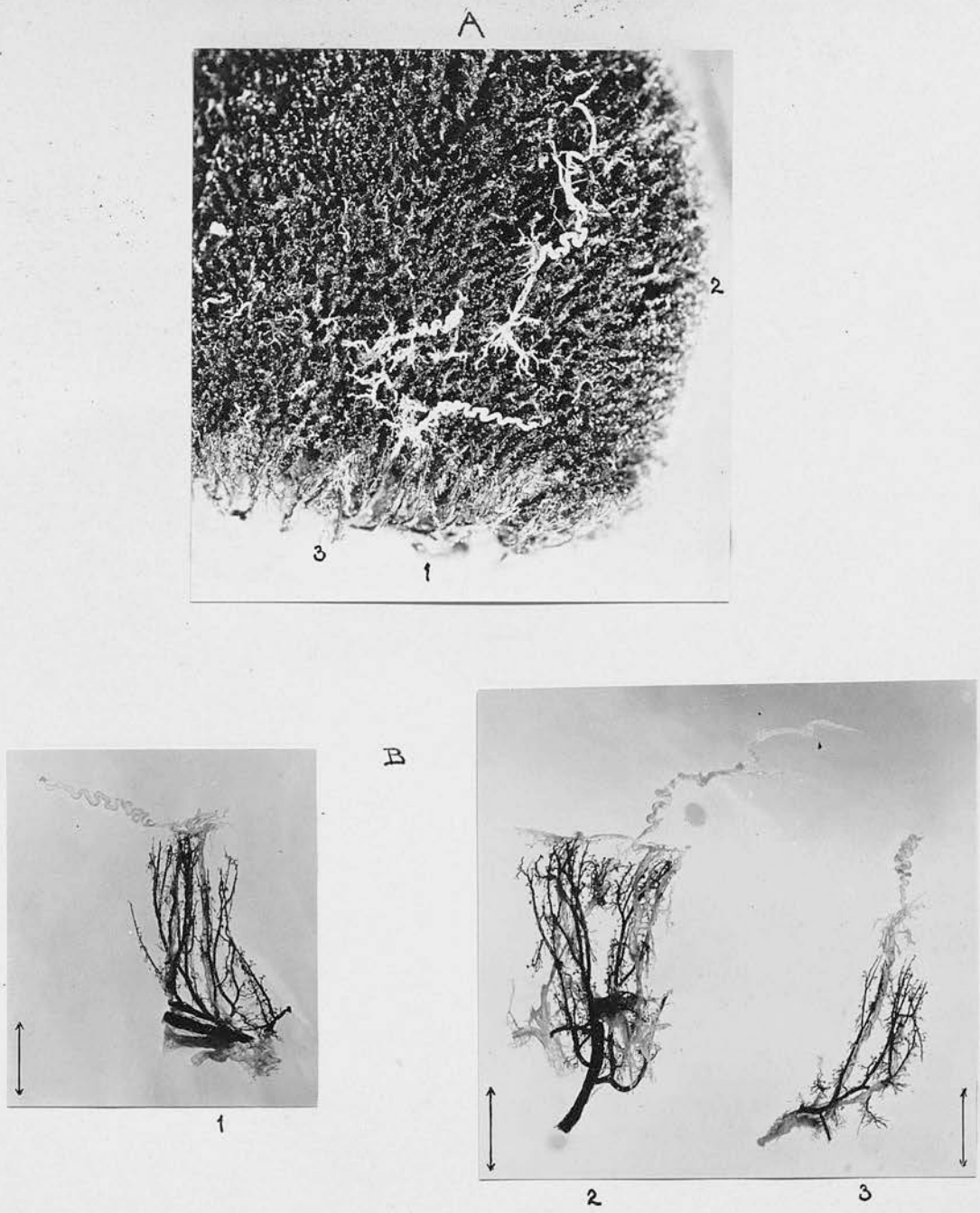


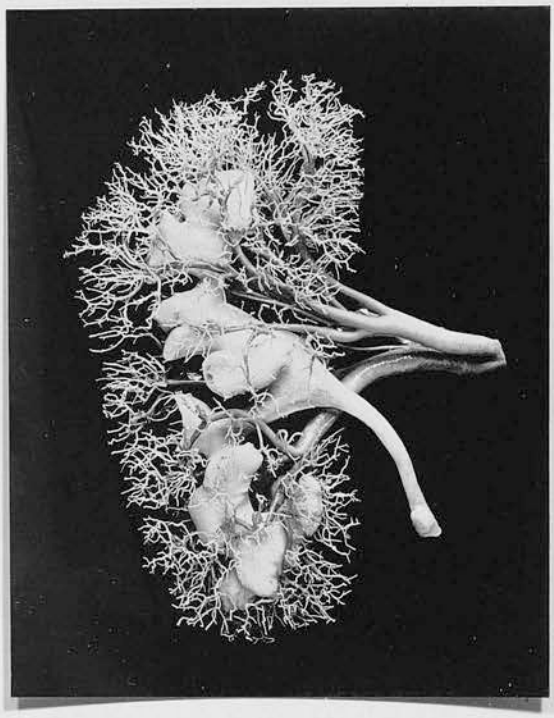
Fig. 16. - Stellate Veins with Entering Capsular Branch. Human kidney - adult.

Injection: Fairly complete arterial and venous.

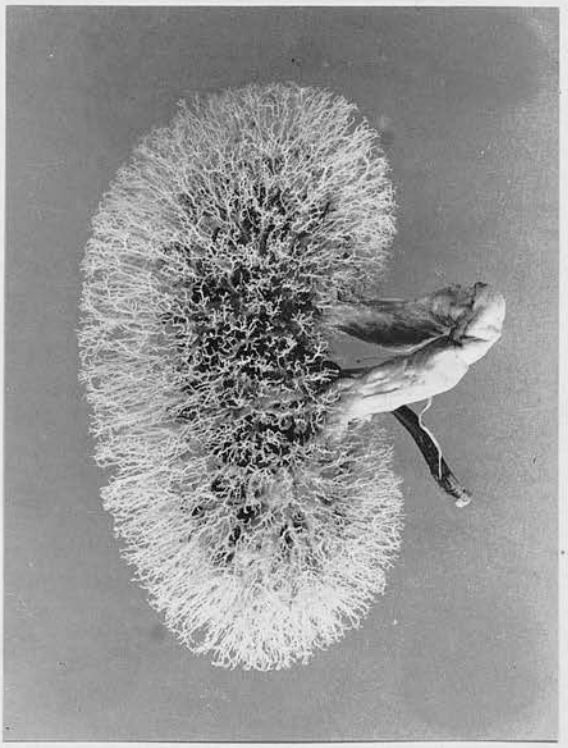
A. Portion of a gross specimen, showing surface of cortex and the stellate veins with entering branches, in situ. Glomerular bearing interlobular arteries may be seen at lower portion of picture.

B. The same stellate veins dissected out to show relationships more clearly. Numerals identify the respective specimens.

Fig. 17. - Kidney of deer.
Injection of artery (A), vein (V) and ureter (U).

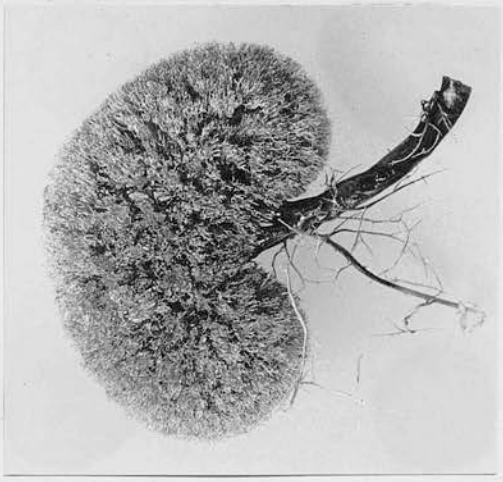


A

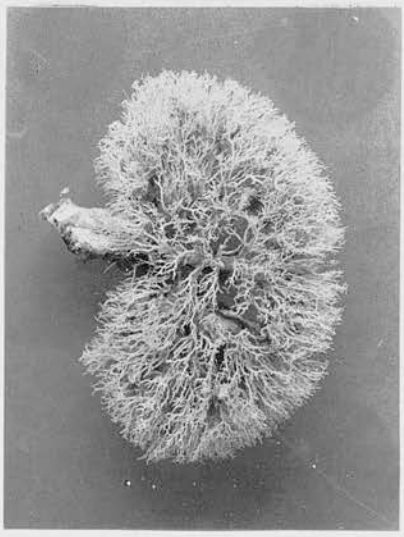


B

Fig. 18. - Kidneys of pig.
A. Arterial and ureteral injection.
B. Venous and ureteral injection.
Note especially the type of renal pelvis and its rough resemblance to that of man.
The interlobular vessels are relatively longer than in other animals.



A



B

Fig. 19. - Kidneys of sheep.
A. Arterial injection.
B. Venous injection.
Similar in structure to those of the dog.

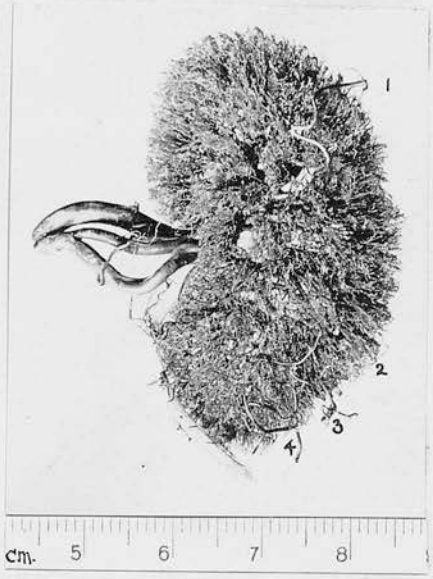


Fig. 20. - Kidney of dog.
Injection of ureter and arterial system.
This specimen presents four comparatively large sized perforating capsular arteries.
The arterial branch accompanying the ureter is present.

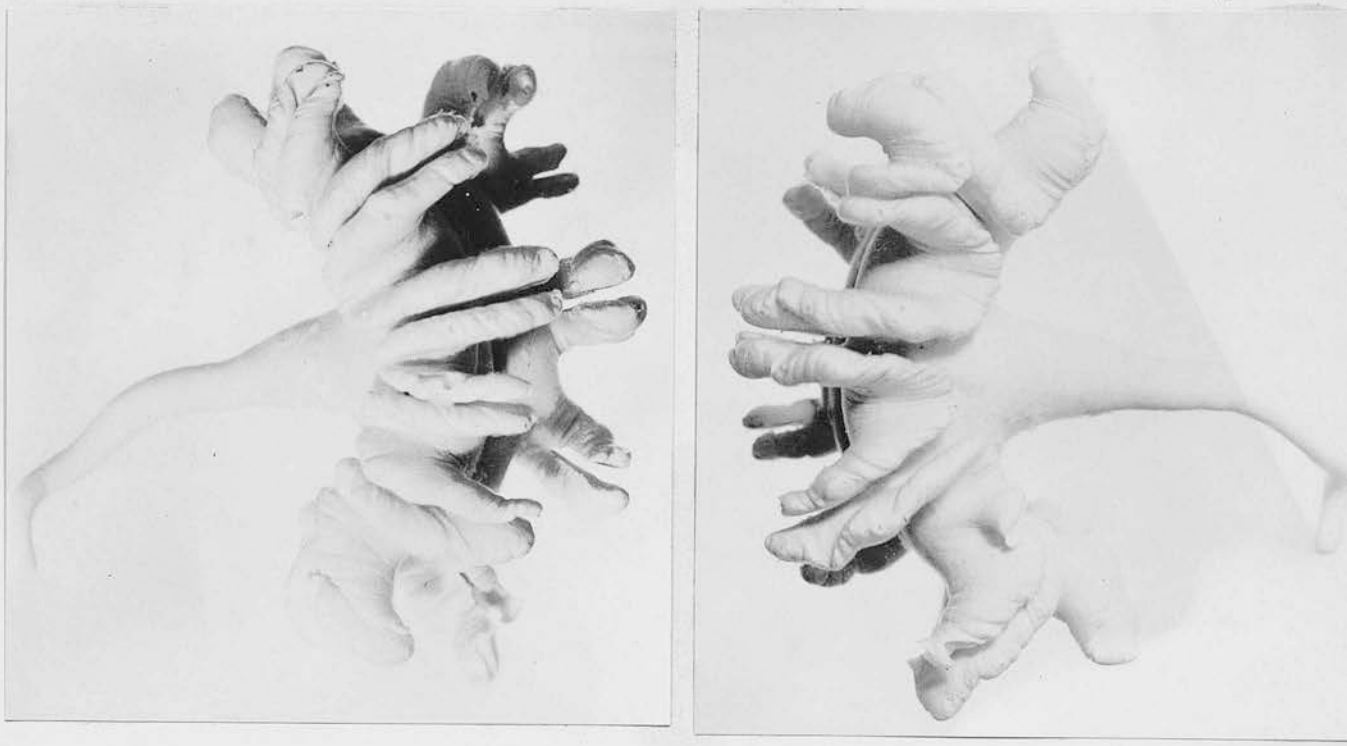
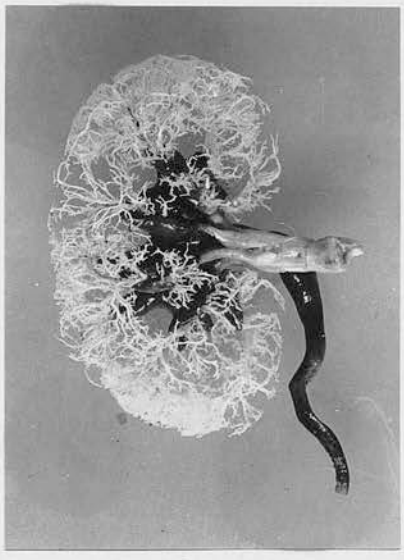


Fig. 21. - The Renal Pelvis in the Dog.
From a wax injection prepared by the method advocated by Groetzel (Frankfurter Zeitschrift f. Pathologie, VIII, 1911, pp. 34-79).
The leaf-like type of pelvis provides gutters or grooves along which the main vessels pass.
Note small grooves for smaller branches and Y-shaped grooves for a bifurcating trunk.
To be compared with Fig. 22.

Fig. 22. - Kidney of dog.
Injection of ureter and pelvis with the arterial system (coarse).
This illustrates graphically the main arterial distribution in relation to the pelvis. Note the comparatively narrow groove in which the vessels lie between the "leaves" of the calyces. An occlusion of the ureter with consequent hydronephrosis would rapidly distend these "leaves" and tend to subject the vessels to compression.

A



B

Fig. 23. - Kidney of dog.
Injection of ureter and venous system.
A. Dissection to show medullary aspect of two calyces. From each emerge arcuate venous trunks. Into these arcuate trunks there pass from above stellate veins (1) and interlobular veins (2). The small anastomotic venules passing downwards from the under side of the stellate branches are shown.
B. Gross specimen. Veins white; ureter and pelvis dark.
The general distribution of the main trunks in relation to the grooves of the renal calyces is evident. The superficial stellate veins, then the interlobular radicles passing into the arcuate trunks can also be made out.

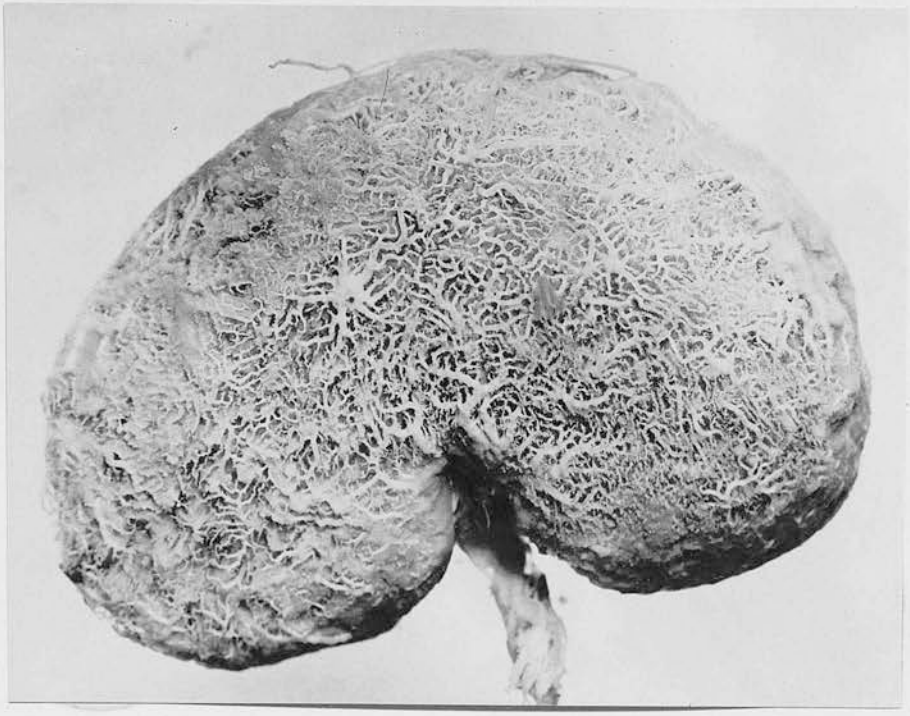
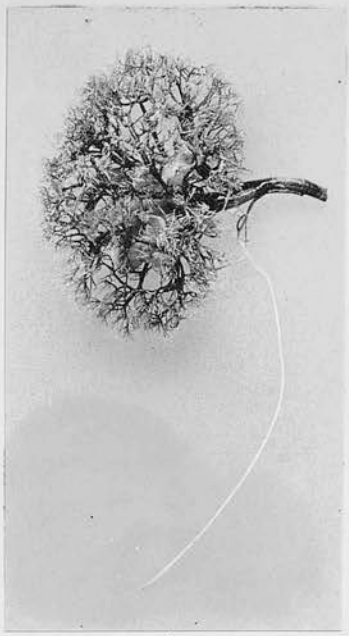
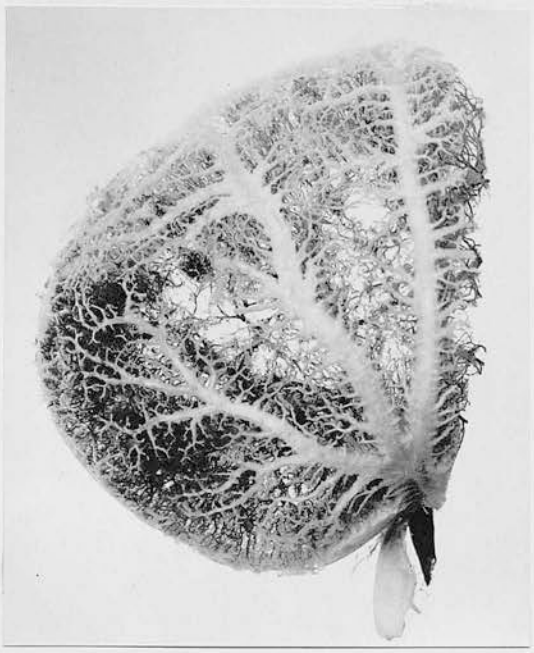


Fig. 24. - Kidney of dog.
Injection: Complete venous.
Specimen subjected to only sufficient "washing" to demonstrate the superficial venous system.
The complex network of subcapsular drainage in the dog's kidney is here well shown.
The small tortuous radicles empty into the limbs of stellate veins and these in turn into the arcuate system, etc.
It will be noted that this superficial venous system of the dog is more complete than in man.
The stellate veins above appear to each drain a larger area of cortex -- their branches are longer.

Fig. 25. - Kidney of young dog.
Venous injection.
The external system of stellate veins has in this instance been elaborated and appears to be simulating an approach to the cat type.
Original preparation by A. E. Belt.



A



B

C

Fig. 26. - Kidney of cat.

A. Gross arterial injection with pelvis.

B. Portion of gross specimen - arterial and venous injection.
The main channels of the superficial venous system show up in contrast to the subjacent arterial system (dark).

C. The renal pelvis. The specimen has been dissected practically clear of an accompanying venous injection. The type of pelvis resembles that of the dog and rabbit.
The cat of all animals so far investigated possesses relatively the smallest size of ureter.

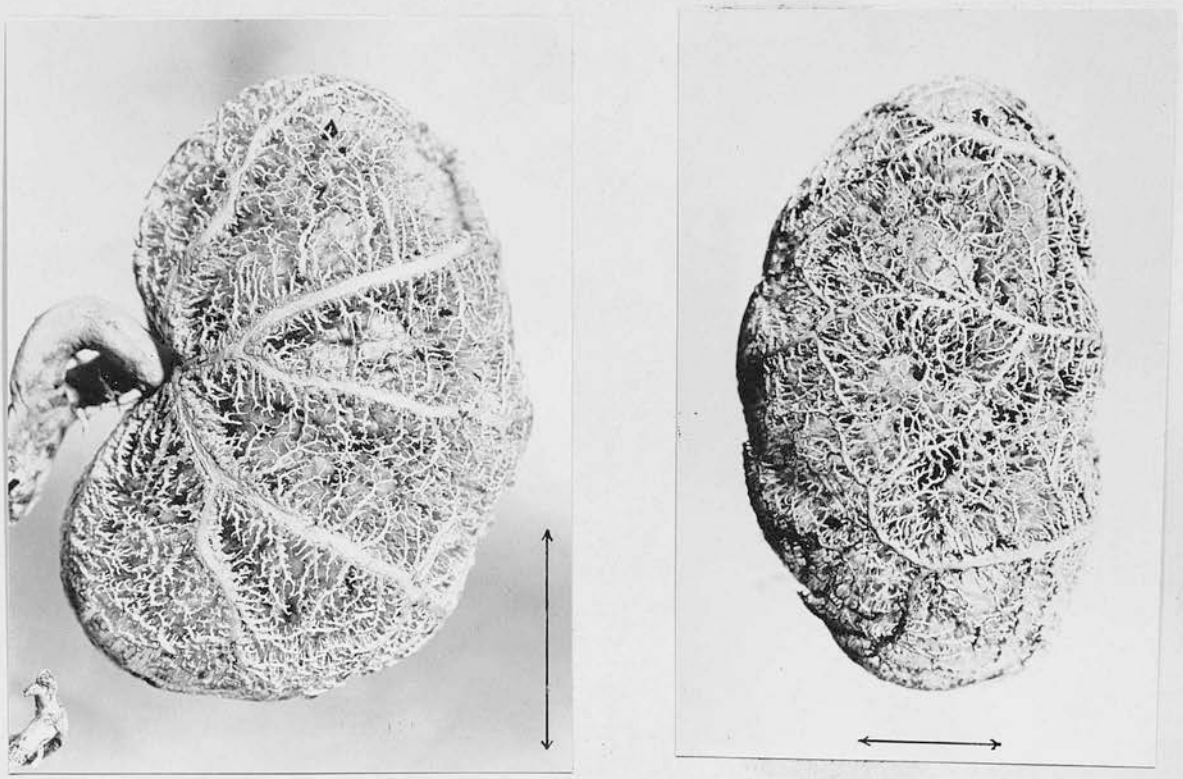


Fig. 27. - Kidneys of cat.
Venous injection.
Showing the separate superficial venous system emptying directly into the renal vein.
A lateral and end view of specimens prepared by Dr. A. E. Belt.

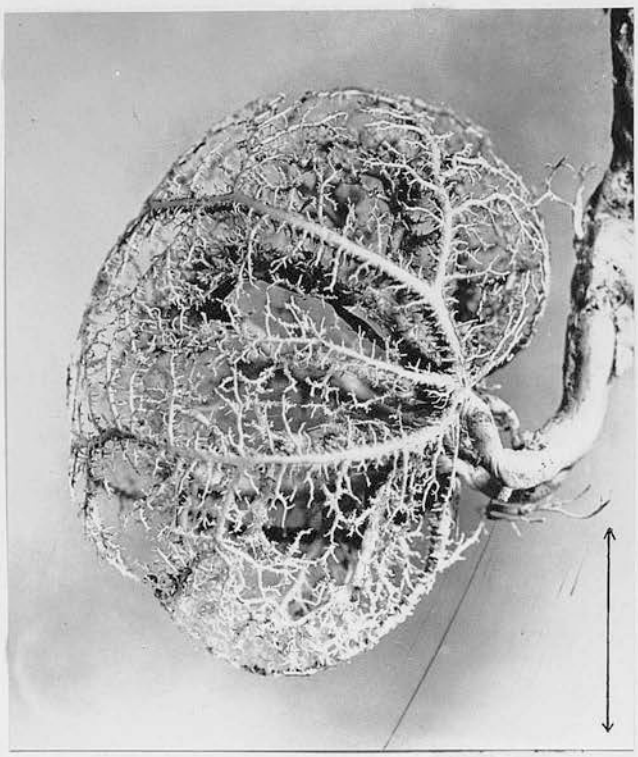


Fig. 28. - Kidney of cat.
Venous injection.
Shows clearly the two distinct venous systems - the external and the internal.
From a specimen prepared by Dr. A. E. Belt.

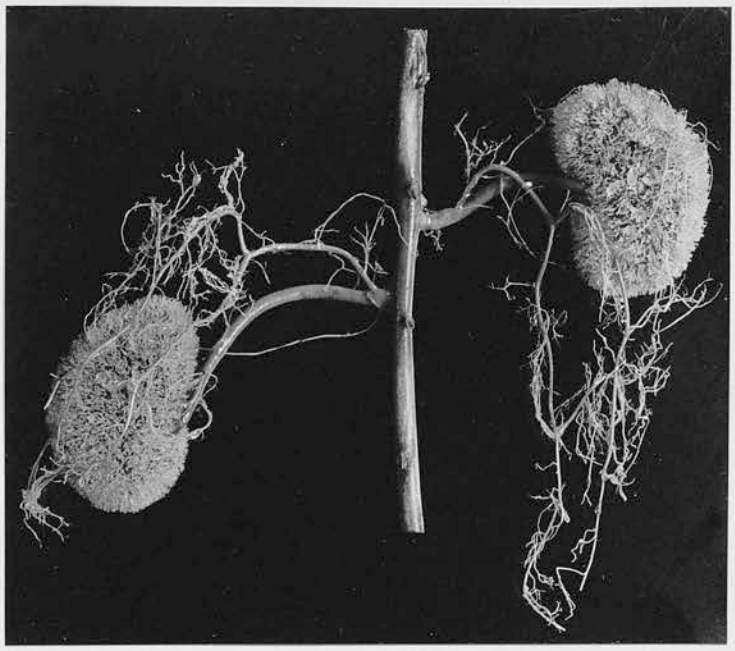
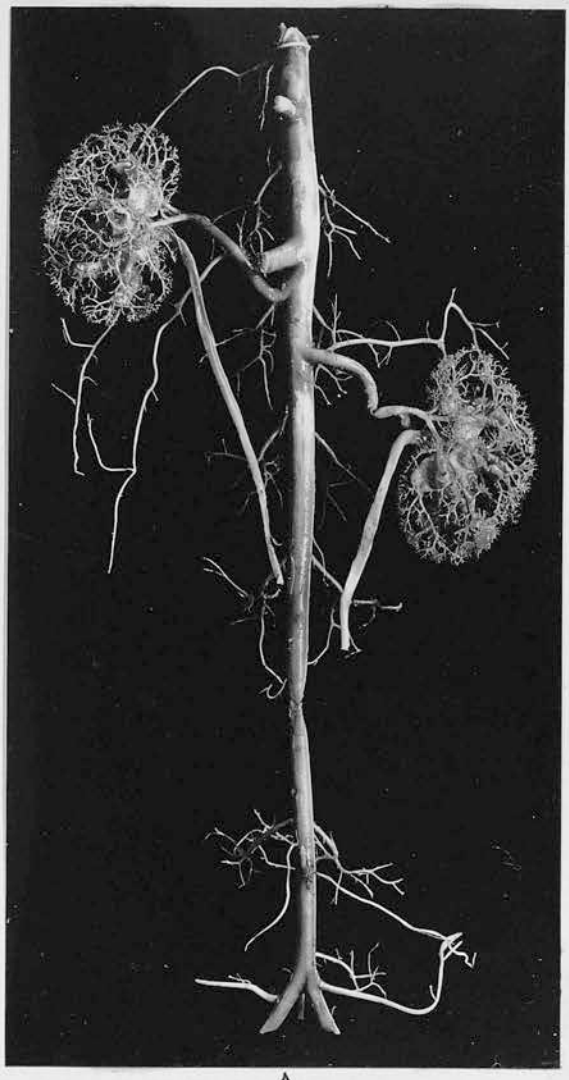


Fig. 29. - Kidneys of rabbit.
Arterial injection made in situ.
All branches of abdominal aorta, excepting those intimately related to the kidneys, have been resected. Specimen seen from dorsal aspect.
The left kidney in such animals is usually much lower than the right, and in shape tends to be rather pear shaped - upper pole presenting the smaller end.



A

B

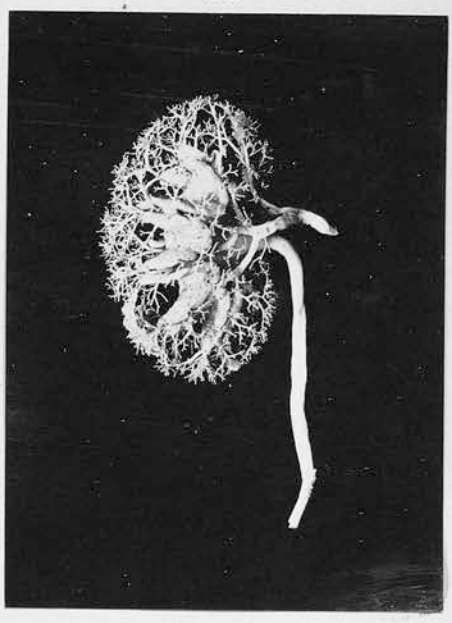


Fig. 30. - Kidneys of rabbit.
A. Complete gross arterial and ureteral injections in situ.
B. "Close up" of rabbit kidney showing type of arterial distribution in relation to pelvis. The main arterial branches lie in the grooves formed by the leaf-like calyces.

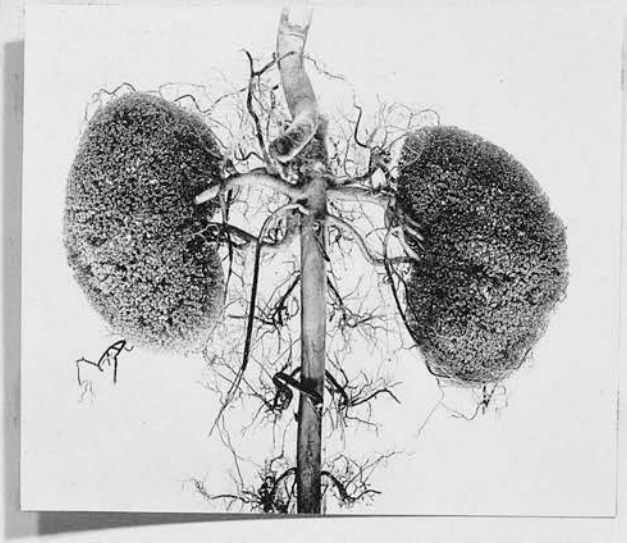


Fig. 31. - Kidney of guinea pig.
General arterial injection in situ.
Superior and inferior mesenteric vessels removed. The distribution of the renal vessels is subject to much variation in this species of animal.
Note the main vessels, how they differ on each side in this specimen.

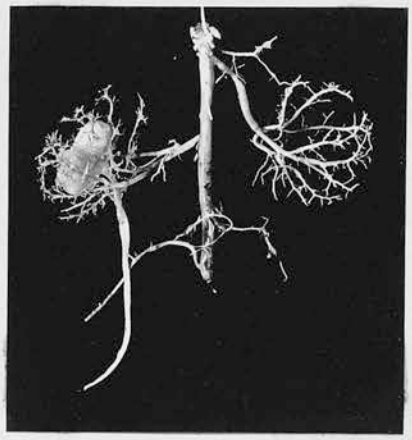


Fig. 32. - Kidneys of rat.
Arterial injection made in situ.
Left ureter also injected.
Specimen seen from dorsal aspect.
The renal arteries show a marked difference in levels of origin.
The rat's renal pelvis - not well shown here - resembles the other

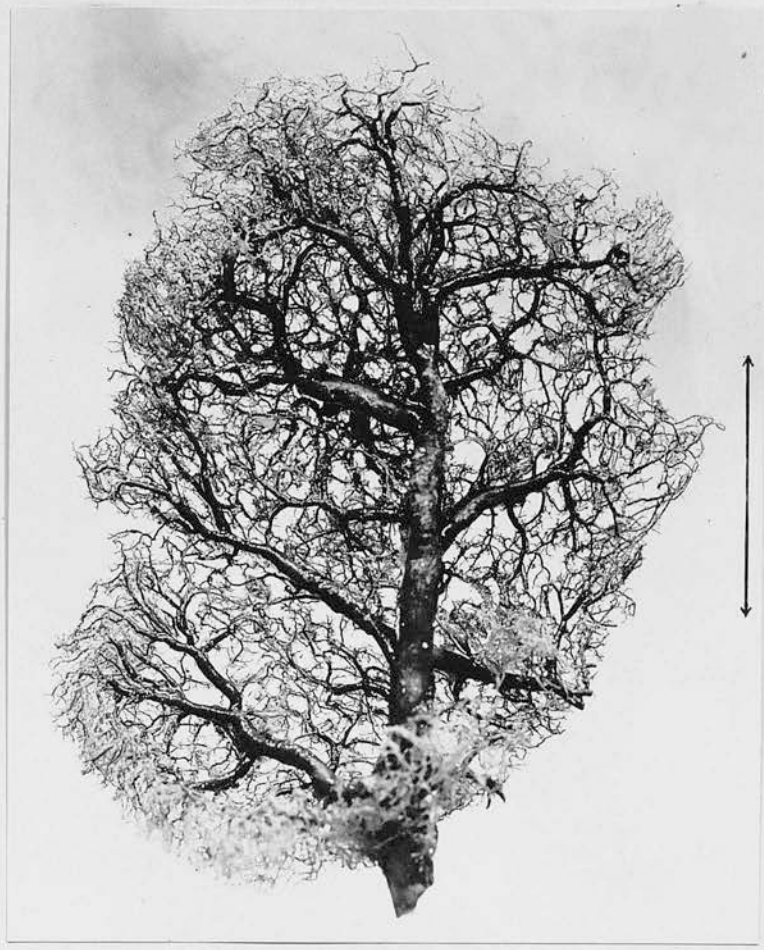


Fig. 33. - Interlobar Artery (Human) Isolated.
Seen from medullary aspect, showing complete system of ramification.
The peripheral interlobular branches are not seen except at one or two places, since they are pursuing a course directly away from the observer.

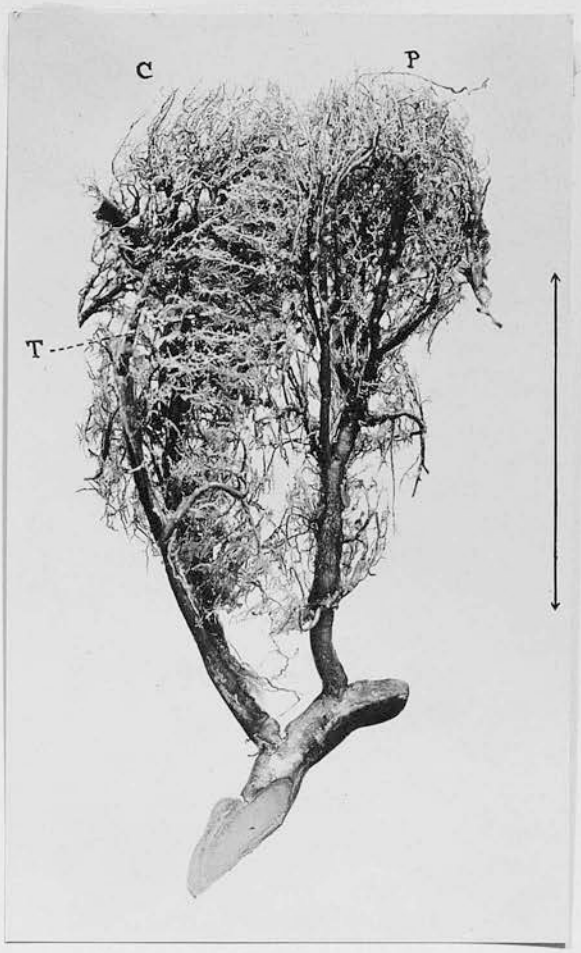


Fig. 34. - Transverse Cortical Column (Human).
Two interlobar arteries, with their entire ramifications, shown arising from a portion of the renal trunk. Between the vessels can be seen the interlobular arteries arranged transversely and parallel to the surface of the cortex (C).
A slight furrow can be noticed at the cortex immediately above the transverse column (T), and from it there emerges a perforating capsular artery (P).

Fig. 35. - A Main Trunk with its Arcuate Artery (Cat).

A. Main trunk.
B. Arcuate artery.
C. Interlobular arteries.
D. Glomeruli with efferent vessels (medullary type).
M. Position of medulla in relation to specimen.

The arrangement of branching is here shown in its simplest form. It is the type present in one-lobed kidneys - sheep, deer, dog, cat, rabbit, rat, etc. The main trunk gives off several large branches at an acute angle; the arcuate vessel acts similarly at first but later, it will be noted, the angle increases till ultimately near its termination (not shown in this specimen) almost a right angle is reached.
The specimen was prepared to show the coarser ramifications, hence only a few glomeruli around the arcuate artery and its main subdivisions can be identified. Some of these, however, show efferent vessels passing over the arcuate trunk to gain the medulla. It will be observed that there is no suggestion of any branches passing directly from the concavity of the arcuate vessel towards the medulla, i.e., no arteriae rectae verae.

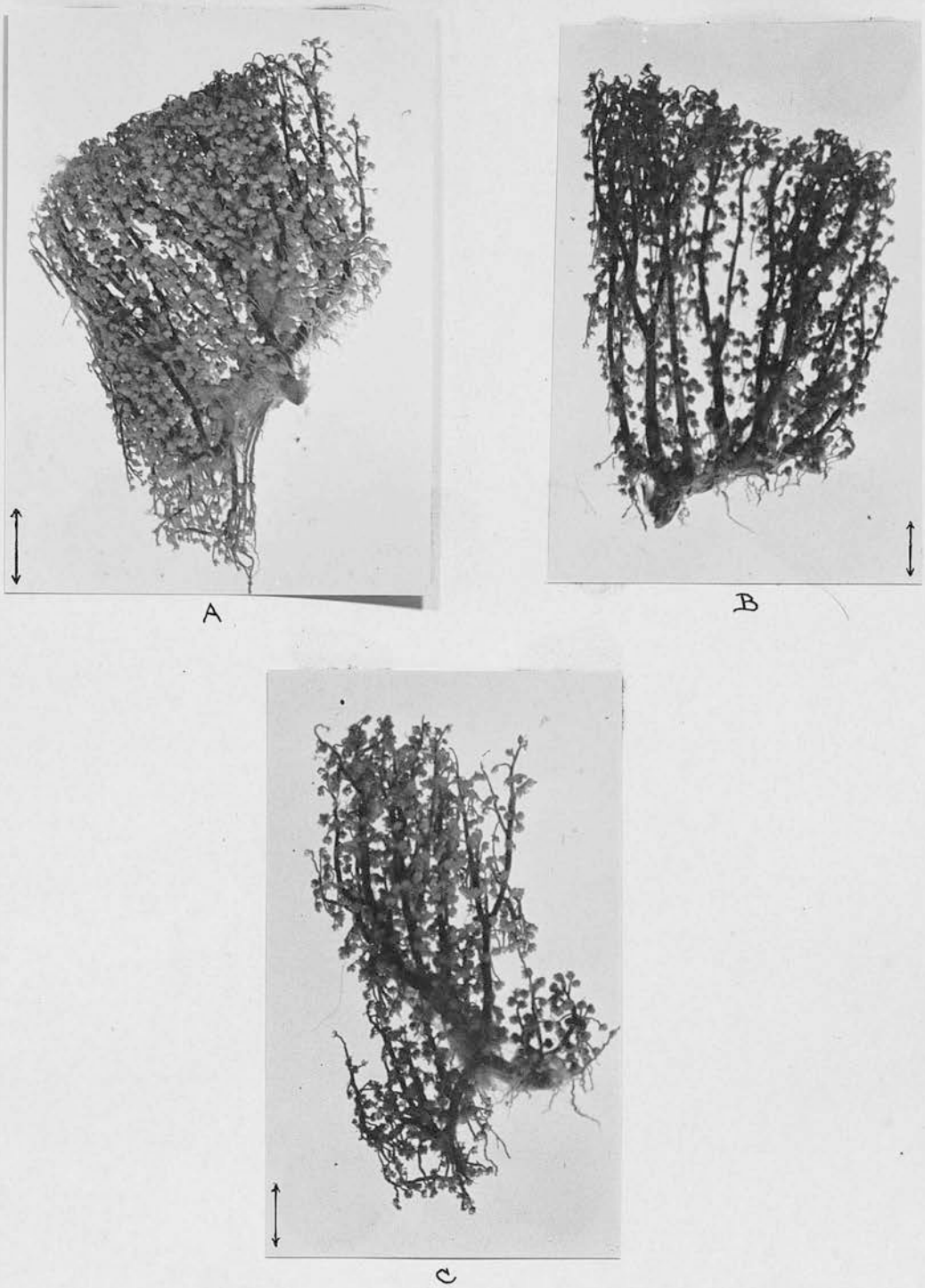
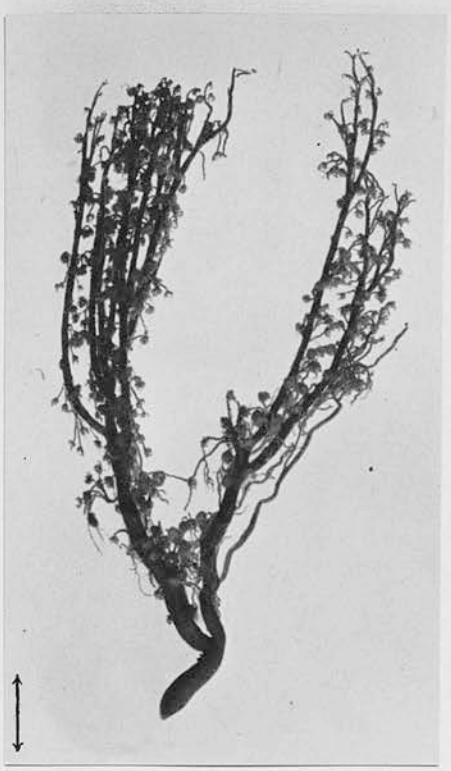
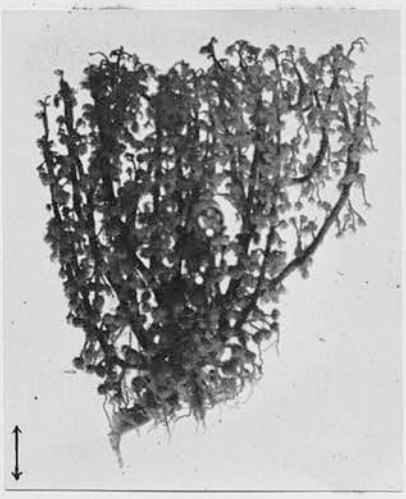


Fig. 36. - Interlobular Arteries (Human). Arising from terminal arcuate arteries. Note the "descending" type of branch in A and C.





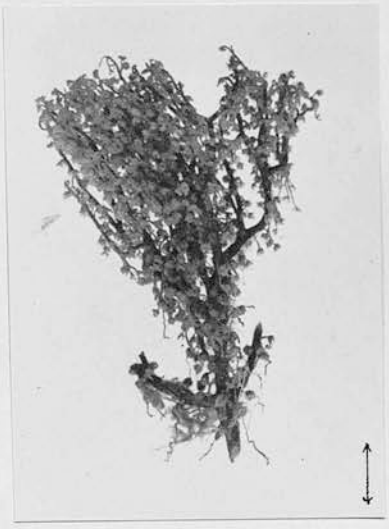
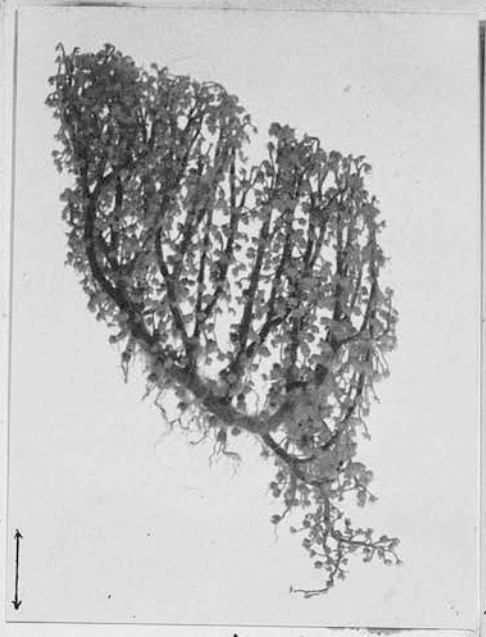
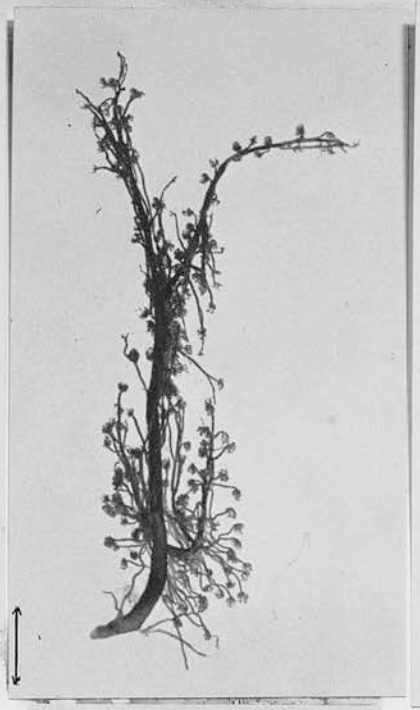


Fig. 37. - Interlobular Arteries (Human).
Showing various modes of distribution.



A



B.

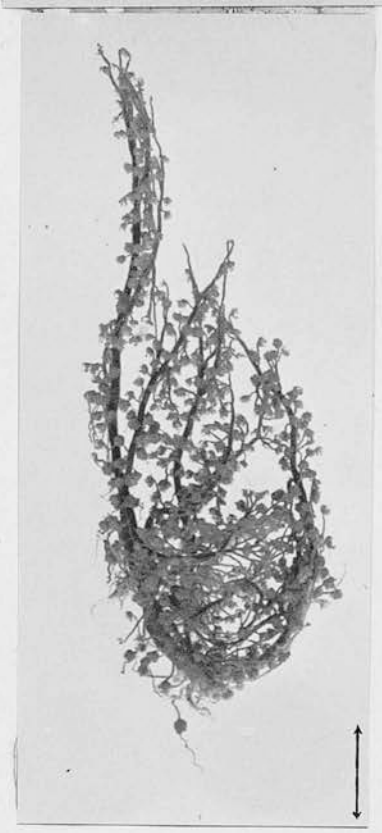
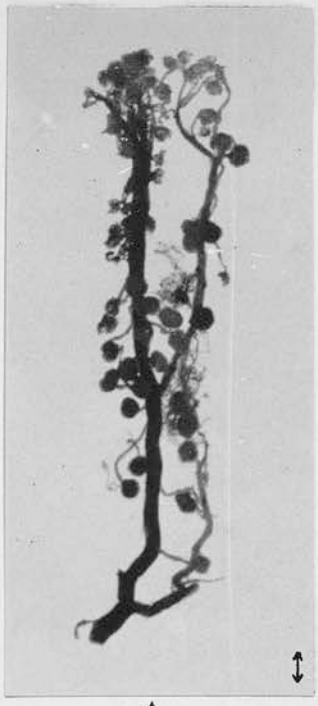


Fig. 38. - Interlobular Arteries (Human).
Eccentric forms found chiefly at points where adjacent lobes meet. Note in A and B the numerous glomeruli with efferent vessels which arise from the terminal arcuate branch.

Fig. 39. - Arcuate Vessel and Interlobular Arteries (Human). Showing efferent glomerular vessels (arteriae rectae) passing over and around the arcuate vessel in their downward course. A large number of the glomeruli are imperfectly injected and show reticulation.

A. Arcuate artery.
B. Interlobular arteries.
C. Efferent glomerular branches (arteriae rectae).

Fig. 40. - Interlobular Arteries (Dog).
A small arcuate subdivision is shown terminating by branching into interlobular arteries. The injection has not been fine enough to show efferent glomerular vessels but demonstrates various types of branches and the diverse positions assumed by glomeruli and their afferent vessels. A "fresh growth" type of branch is prominent, coming off almost at right angles to the parent stem and ending in a tuft of afferent glomerular vessels. Several long-stalked glomeruli can be seen arising also from the main stem.



A

B

C

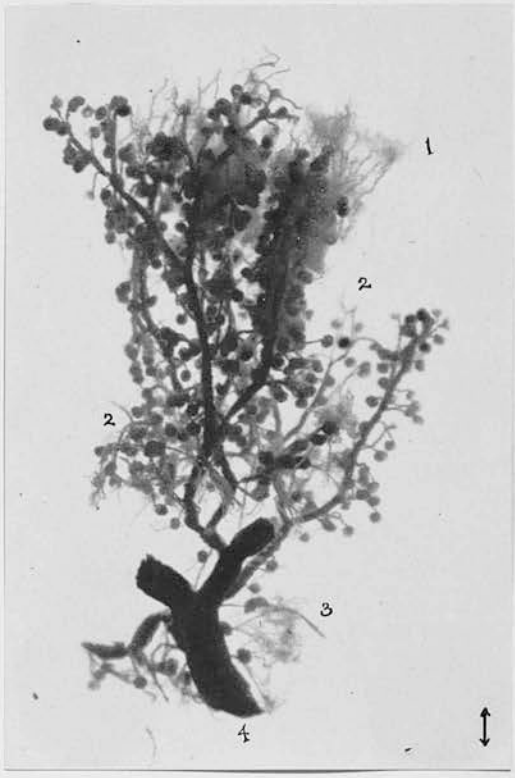
Fig. 41. - Interlobular Arteries (Dog).
Complete fine arterial injection.

A. Detail of an interlobular artery. Some of the glomeruli are not well filled and show an open capillary network. Only an occasional efferent vessel is present.

B. Similar to A in that many glomeruli are imperfectly injected. Bundles of straight efferent glomerular vessels proceed from the lower portion of the specimen. (In the process of teasing and dissecting out, then ultimately mounting in gelatin, it is extremely hard to prevent these minute capillary vessels from becoming twisted and damaged).

C. The termination of an arcuate artery by a sudden upward bend into interlobular vessels.
Note the number and types of glomeruli. Peripheral glomeruli not at all well injected.

A



B

Fig. 42. - Ultimate Vascular Distribution in Cortex (Dog).

1. Efferent glomerular vessels proceeding to cortex corticis, characteristic of this type. (Better shown in B).
2. Efferent glomerular vessels of cortical type.
3. Efferent glomerular vessels of medullary type. Note the numerous varieties of glomeruli respresented in both A and B.
4. Termination of arcuate vessels from which rise the interlobular arteries.

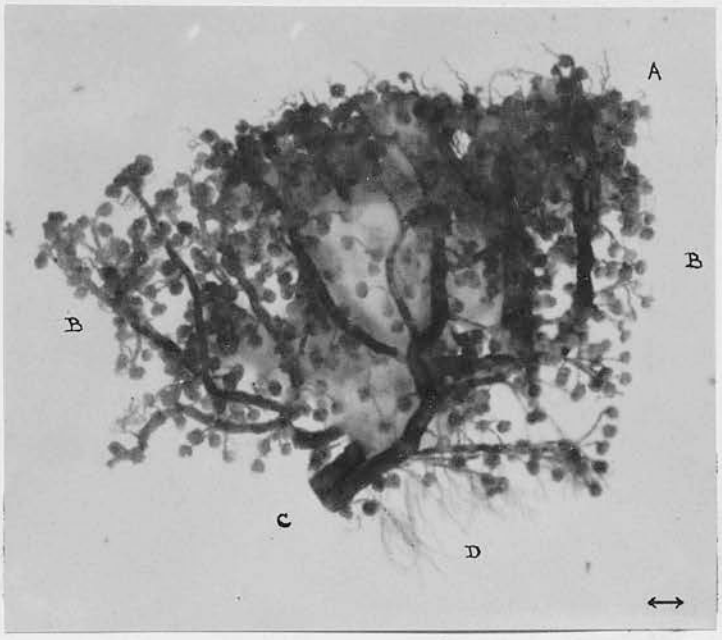


Fig. 43. - Small portion of Cortex (Dog).
Injection: Complete fine arterial.
A. Efferent glomerular vessels passing vertically upwards into cortex corticis.
B. Interlobular glomerular bearing arteries. (Some of the digested parenchyma has not been completely "washed" out and shows as a white opacity in the middle portion of the specimen).
C. Terminal portion of an arcuate vessel.
D. Numerous glomeruli of "medullary" type. Their bundles of straight efferent vessels are seen taking a downward medullary course.

Fig. 44. - Cortical Distribution (Rabbit).
A group of interlobular arteries.
The glomeruli appear relatively large and have short afferent vessels.
The glomeruli of the "medullary zone" seem bigger than the others and send downward well formed arterae rectae.

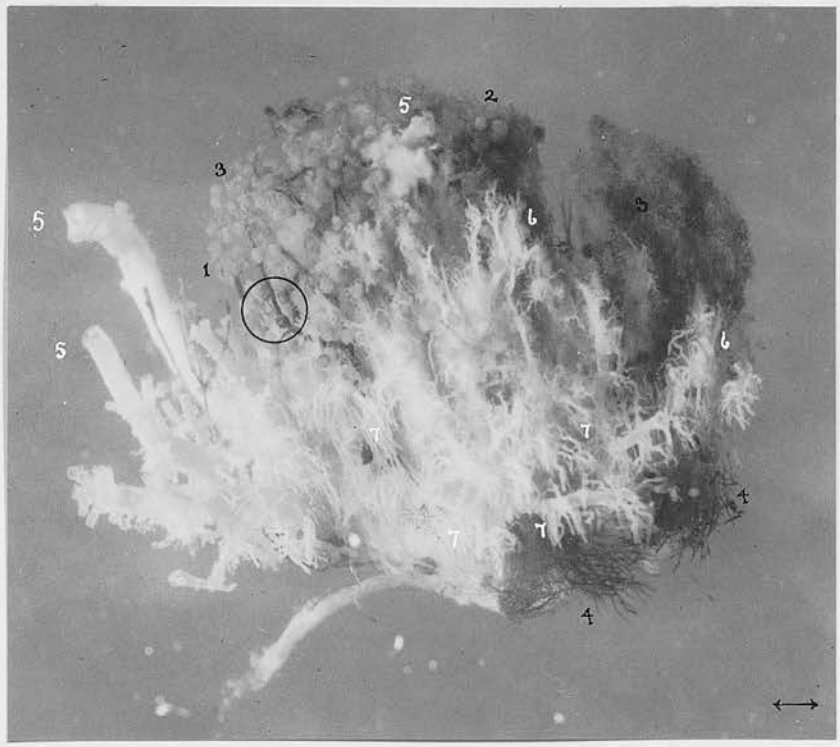


Fig. 45. - Portion of Cortex (Dog).
Injection: Fine arterial (dark) and venous (white).
Shows:

1. Interlobular glomerular bearing arteries.
2. Subcapsular type of efferent glomerular vessels.
3. Cortical type of efferent glomerular vessels. (One glomerulus showing 2 efferent branches is ringed in black).
4. Medullary type of efferent glomerular vessels or arteriae rectae.
5. Imperfect trunk of stellate vein.
6. Interlobular veins.
7. Straight vessels - venae rectae - joining up to small trunks of the arcuate vein. The main trunk is somewhat obscured.
   Note the size and character of the venae rectae as compared to the arteriae rectae.

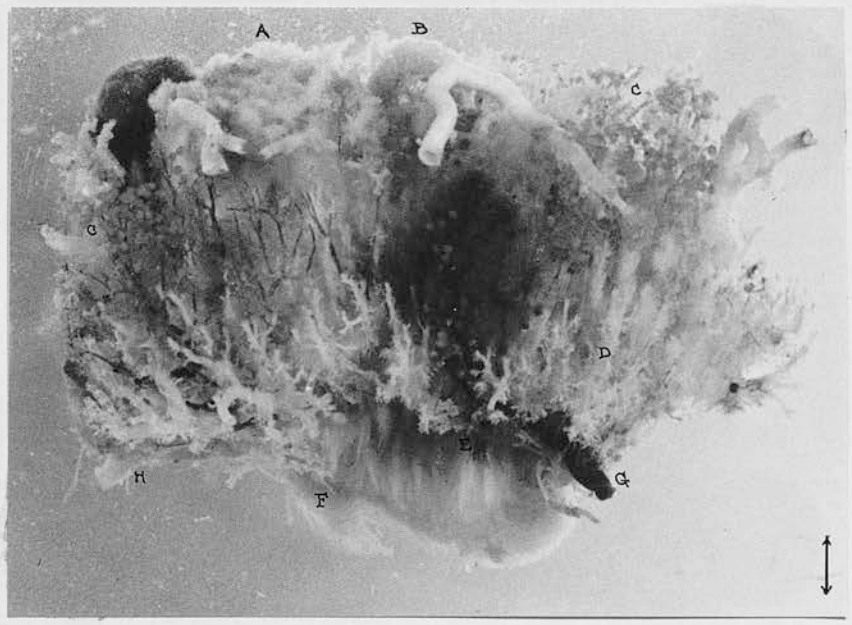


Fig. 46. - Portion of Renal Cortex (Dog).
Injection: Fine arterial and venous.
A. Extremely fine capillary plexus shown in cortex corticis.
B. Stellate veins.
C. Interlobular arteries.
D. Interlobular veins.
E. Arteriae rectae.
F. Venae rectae.
G. Arcuate artery.
H. Arcuate vein.

Fig. 47. - A section of kidney showing fine arterial distribution, prepared by injection of coloured gelatin, then sectioning and clearing. Glomeruli with efferent capillary plexuses can readily be identified.
To one side of the centre of the field there is a more or less circular deficiency, and leading down from this is a dense mass of fine, straight vessels.

Fig. 48. - Subcapsular Glomeruli on terminal portion of Interlobular Artery.
Two show efferent vessels, characteristic of the type, which enter and supply the cortex corticis.
Note the appreciable distance each efferent vessel ascends before breaking up into a capillary plexus.

A. Glomerulus
B. Efferent vessel
C. Plexus of capillaries.

Actual size at right-hand lower corner.

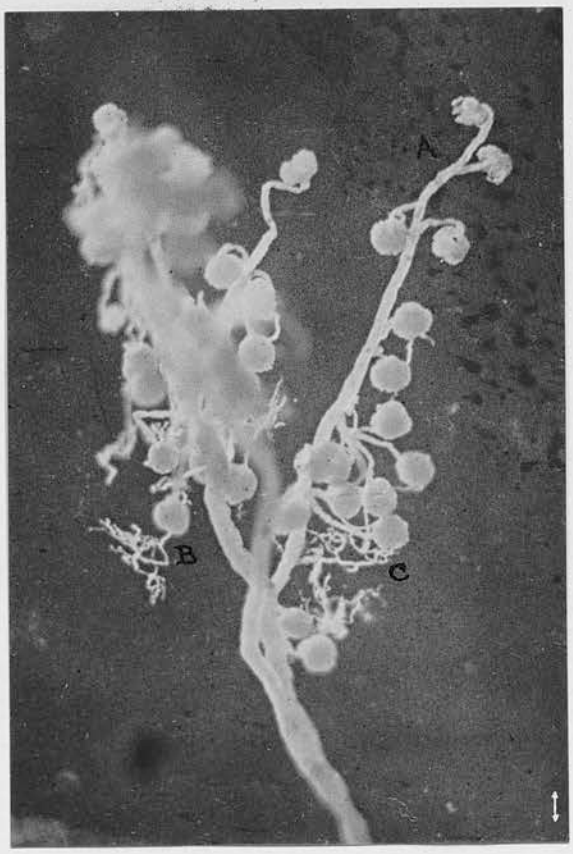


Fig. 49. - The terminal branches of an interlobular artery, showing -

A. Branch ending in one glomerulus.
B. Glomerulus with efferent vessel of cortical type.
C. Direct nutrient vessel coming off in place of the usual afferent glomerular branch.

Actual size shown at right-hand lower corner.

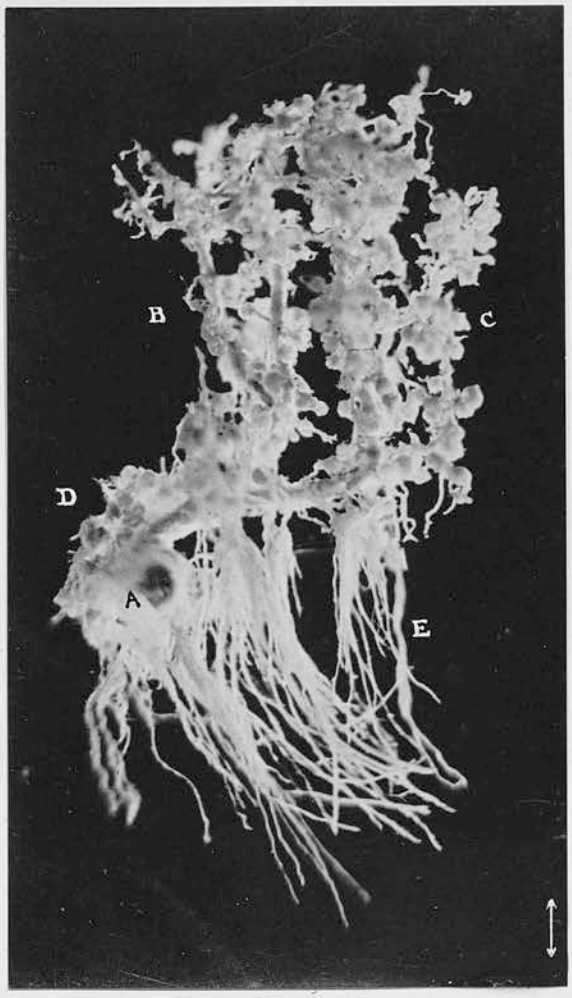
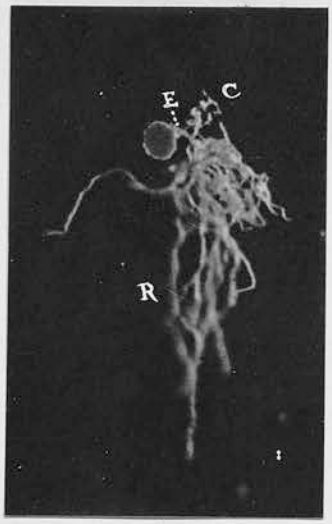


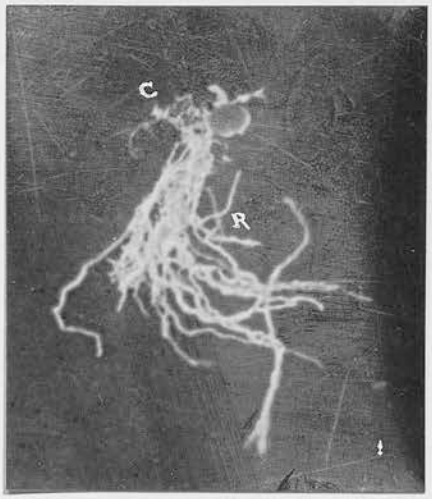
Fig. 50. - Arteriae Rectae (Human).
A terminal portion of an arcuate artery (A) showing -

B. Interlobular branches.
C. Cortical glomeruli.
D. Medullary glomeruli with arteriae rectae.
E. Arteriae rectae. ("Arteriae Rectae Spuriae.")

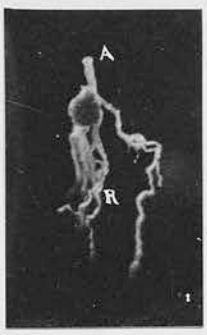
A graphic impression is here obtained of the numerous bundles of efferent vessels as they stream downwards into the medulla.



A



B



C

D

Fig. 51. - Glomeruli.
A & B. Represent examples of the cortico-medullary type. The single efferent vessel (E) soon undergoes subdivision. The majority of the efferent branches form arteriae rectae (R), whereas a few immediately break up into a capillary plexus of the cortical type (C).
C & D. Medullary type showing arteria recta (R). The larger entering afferent vessel (A) is well shown.

Note the actual size of these structures. Their vertical dimensions are rendered in white ink at corner of each picture.

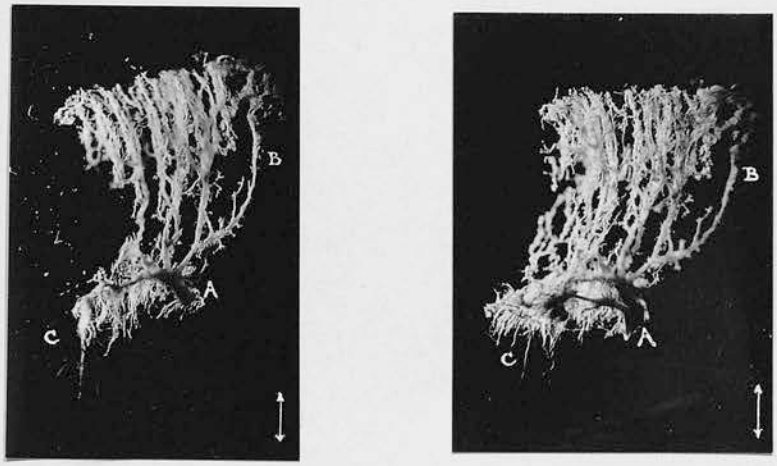


Fig. 52. - Portion of Arcuate Vein (Human). Showing interlobular veins (B), and venae rectae (C) entering directly into the medullary aspect of the arcuate vein (A).

Arterial Distribution of the Kidney. (Semi-diagrammatic).

Constructed on the findings of the present investigation.

(A) Capsule.
(B) Cortex corticis or subcapsular zone of cortex.
(C) Cortex proper.
(D) Medullary zone of cortex.
(E) Medulla.

1. Arcuate artery.
2. Interlobular artery - various types.
3. Interlobular artery ending by supplying four afferent glomerular vessels.
4. Interlobular artery continuing through cortex as perforating capsular artery.
5. Interlobular artery terminating directly as a nutrient vessel in the cortex corticis.
6. A "new shoot" or "fresh growth" type of branch.
7. A direct nutrient branch from an interlobular artery.

A. The efferent glomerular vessel to the cortex corticis, or subcapsular type.
B. The efferent glomerular vessel to the tubules - cortical type.
C. The cortico-medullary type of efferent glomerular vessels.
D. The medullary type of efferent glomerular vessels with bundles of straight branches (arteriae rectae) passing down into medulla.
E. Glomerulus with short afferent vessel arising from arcuate trunk.
F. Glomerulus with medium length of afferent vessel.
G. Glomerulus (small) with very long afferent vessel arising from arcuate trunk.
H. 'Afferent vessel' breaking up into arteriae rectae without any evidence of glomerulus, but otherwise simulating a glomerular-bearing vessel.